Faculty of Science & Engineering

Saudi Female High School Students' and Teachers' Understandings of Thermal Concepts

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Human Ethics (For projects involving human participants/tissue, etc) The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number # SMEC-09-140

Signature: ………………………………………….

Date: 04/12/2018

Statement of contribution by others

With the exception of the material detailed below, this thesis is entirely my own work compiled and drafted with assistance from my supervisor panel of Professor David Treagust and Associate Professor Marjan Zadnik.

The content of Chapter 6, Table 6.10, page 174-175, 1st column labelled as ‘Misconceptions’ is reproduced from Yeo and Zadnik (2001, *The Physics Teacher, 39*(8), p. 498). The 3rd column of Table 6.10 labelled as ‘Option’ is reproduced from Louzada, da Fonseca Elia, and Sampaio (2015, *Brazilian Journal of Physics, 37*(1), p. 3). In addition, figure 6.4 is reproduced and modified from Chi (2013), *International Handbook of Research on Conceptual Change,* p. 58).

In addition of that, some aspects of the thesis have been presented in multiple conferences as stated below:

The content of Chapter 5 was reproduced as a presentation/abstract entitled “High School Students’ Understandings of Thermal Concepts” at the Australian Association for Research in Education (AARE, 2015) conference at the University of Notre Dame, Fremantle, Western Australia.

The content of Chapter 5 was reproduced as a presentation/abstract entitled “An Arabic Culture Model of Conceptual Change” at the 2nd Inter-regional Research Conference on Science and Mathematics Education & Interfacing Arab and Asia-Pacific Science and Mathematics Education Research 2018, held in Beirut, Lebanon at the American University of Beirut (AUB).

Different aspects of Chapter 5 content were reproduced in a presentation/abstract entitled “An International Comparison of Students’ Understanding of Thermal Concepts” at the annual meeting of the American Educational Research Association 2019, held in Toronto, Canada at the American Educational Research Association.

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Another aspect of Chapter 6 was reproduced as a poster/abstract entitled “An Arabic Culture Model of Conceptual Change” at the combined 2nd International Conference on Science, Technology, Engineering and

Mathematics Education (ICSTEM2018), The 5th International Innovative Practices in Higher Education Expo (I-PHEX 2018), The 1st Innovative Practices in Education Expo (I-PEX 2018) & Post Conference Workshop on STEM Education, held in Sunway Putra Hotel, Kuala Lumpur, Malaysia at the Universiti Teknologi Malaysia (UTM).

(Signature of Candidate)

(Signature of Supervisor)

Abstract

Students, pre-service teachers, and even practicing science teachers can struggle to make connections between scientific concepts and everyday experiences. Studies have identified students' misconceptions in science where guessing is often employed. Investigations of scientific misconceptions amongst pre-service teachers majoring in science have showed that errors were caused by (a) no prior knowledge of the concept, (b) little prior knowledge of the concept, (c) faulty knowledge (misconception) and (d) initial incorrect concepts. Scientific language, or lack thereof, has been identified as a contributing factor as well.

There is a lack of literature investigating female Saudi students' preconceptions or prior knowledge of scientific concepts, as well as the role of vernacular language, terminology, textbooks, and teachers' practical knowledge. Consequently, this study was designed to investigate the level of thermal energy concepts understood by Year 11 Saudi female students and their teachers. The more specific research questions included the following:

1. What thermal concepts are understood scientifically by Saudi female high school students before and after instruction?
2. What misconceptions are formed by Saudi female high school students about thermal energy before and after thermal energy instruction?
3. What is the level of thermal conceptual understanding exhibited by Saudi female high school teachers?
4. What are the possible sources of Saudi female high school students' misconceptions regarding thermal physics?

To respond to these research questions, the Thermal Concept Evaluation (TCE) instrument, which was initially designed to investigate students' alternative thermal energy conceptions in four categories, was administered to year 11 science major students (n = 742) from five schools and to science teachers (n = 30) from 28 schools who had 1–25 years' teaching experience. The 26-item, multiple-choice, one-tier test covered 35 popular misconception statements. A split-half test was used to examine the reliability of the test. The students participated in pre-test and post-test sessions. A workshop intervention was used to reinforce the teachers' thermal physics

understanding gained during their university studies. Focus group discussions and one-on-one semi-structured interviews were conducted to gather information.

Regarding which thermal concepts are scientifically understood by Saudi female students following instruction, a pre-test and post-test response reflected that the student exhibited up to 75% of the alternative conceptions in all four categories. Ambiguous textbook language, lack of laboratory equipment, use of mostly Fahrenheit and alcohol thermometers, and the inactive role of laboratories may be driving the prevalence of misconceptions and preventing students' understanding from going beyond the superficial.

In terms of the sources of Saudi students 'misconceptions regarding thermal physics, a number of possible reasons were identified and considered. Female Saudi students often have very limited exposure to modern sciences, lack access to laboratories, and Internet and media in schools, and updated science materials that enhance understanding. Furthermore, Modern scientific knowledge revolves around innovations that are usually described in terms that are not used in official or everyday Arabic language. Therefore, culture was considered a factor affecting student misconceptions.

Regarding the level of thermal conceptual understanding exhibited by Saudi female teachers in this study, the results from the teacher workshop, interviews, and focus group discussions revealed a low level of understanding of most thermal-related physics concepts.

Findings from this study indicate the need for appropriate scientific language in school settings, and accurate translation and review of American textbooks into Arabic. Moreover, teachers' knowledge must be taken into account in any study targeting student achievement. The study's limitations include its geographical focus (Eastern Province of Saudi Arabia) and relatively small population sample. Nonetheless, the study has identified factors that may have contributed to incorrect responses identified as misconception on the TCE instrument established in developed countries and based on Western standards. Further work is needed to demonstrate the effect of the sociocultural context on learning and to find a way to accommodate it.

ACKNOWLEDGEMENTS

'"Everybody is a genius. But if you judge a fish by its ability to climb a tree, it will live its whole life believing that it is stupid"' Albert Einstein (Turgut, 2013)

I wish to express my sincerest gratitude to those who supported me during my PhD journey. The top of my thanks are to my extraordinary supervisor Professor David Treagust from the School of Education who was always available to provide his professional feedback to me at any time and for emotionally supporting me during all the hardship times that I went through. My sincerest thanks are extended to my co-supervisor Associate Professor Marjan Zadnik from the Department of Physics who helped instigate the study, my thesis coordinator Dr Brendan McGann for all his excellent administrative support during my study, Dr Mihye Won from the School of Education for her early advice during the supervision of my thesis, Mr. Ian Tsen, the Sponsored Students Coordinator from Curtin's International Office for all his professional support, and Dr A L Chandrasegaran for helping with data analysis. Finally, many thanks to Mr Glen Lawson, the Laboratory Manager for the School of Physics, for preparing some special experiments which were used in the teachers' professional workshops.

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CHAPTER 1
INTRODUCTION

1.1 Discussion of terminology used in this study

As early as the 1970s, there was enormous interest in students' learning of science. This interest brought many definitions to the forefront—such as preconceptions (e.g. Novak, 1987), misconceptions (e.g. Helm, 1980), alternative conceptions (e.g. Driver & Easley, 1978), and children's science (e.g. Gilbert, Osborne, & Fensham, 1982) in order to understand the origin of the ideas that students bring to their classrooms. Posner, Strike, Hewson, and Gertzog (1982) found that those ideas (misconceptions) are robust and difficult to extinguish. Yet, differentiating between those terms is very problematic because some of these ideas are rooted in epistemological and ontological conceptual trees (Gilbert & Watts, 2008).

Alternative conceptions, also known as 'theories-in-action' (Karmiloff-Smith & Inhelder, 2018, p. 3), described knowledge that is generated during a personal experience such as a natural development of human beings (Gilbert & Watts, 2008). In addition, Yeo (2002) referred to students' alternative conceptions as their common experiences when concepts are generated by students to make sense of their world phenomena. Yeo added that students normally are comfortable with their ideas because, from their perspective, they are obvious, sensible, useful, and do not require justification (Yeo, 2002). A trend in educational psychology studies is to consider a student's alternative conceptions as an 'unavoidable and desirable feature of personal experience' (Gilbert & Watts, 2008, p. 67).

In this study, the term misconception will used to refer to students incorrect (inaccurate/ incommensurate) ideas generated by students as a false beliefs, flawed mental models, category mistakes or missing schema due to defective, damaged mental models or incomplete mental models (Chi, 2013; Vosniadou & Verschaffel, 2004).

This chapter serves as an introduction to the thesis by illuminating the relevant details in the following sections: Section 1.2 focuses on the rationale of the study and explains the purposes behind evaluating Saudi female high school students' understanding of thermal physics. Section 1.3 presents the framework for conceptual change and Mental Models (MM) that explain students' misconceptions, Section 1.4 describes the purposes of the study, and Section 1.5 presents the research questions. Next, Section 1.6 explains the significance of the research, Section 1.7 covers the research design in detail, and Section 1.8 describes the structure of the entire thesis and the organization of the responses to the research questions. Finally, Section 1.9 defines some frequently used terminologies.

1.2 Rationale for the Study

Since education for Saudi female students was established about 60 years ago (Hamdan, 2005), teaching and learning in Saudi female schools has been based on traditional teaching methods through lecturing where students play passive roles in the learning process (Hamdan, 2005). In recent years, many changes have been made to the Saudi high school education system to convert it from a traditional education system to a credits system based on American standards (Albadi, Harkins, & O'Toole, 2018). In addition, the new system follows the Student-Centred Learning strategies as explained in the 'Saudi Guide to Secondary Education' report from the Secondary Education Development Project (SEDP) (Al-Roumi & Alshaya, 2010). At the same time, the new Saudi high school physics textbook, for instance, is based on the inquiry-based learning strategy (Zitzewitz, 2008). These changes came about after the unsatisfactory results shown by students in international assessments, such as the Trends in International Mathematics and Science Study (TIMSS), the Progress in International Reading Literacy Study (PIRLS), and the Programme for International Student Assessment (PISA) (Al-Ahmad & Al-Farha, 2012). One new goal of these changes is to improve how students are assessed to ensure that they are equipped with the latest knowledge and understanding. A second goal is to match the American secondary education system with the Saudi system to make it easier to convert graduate qualifications between the two (Al-Roumi & Alshaya, 2010). However, even with Saudi physics teachers applying the most advanced teaching and learning strategies (although not compulsory), the results of Saudi students in these international assessments have remained very low. For example, Saudi students are at the bottom of the TIMSS results, ranking 104 points below the average score in 2015 (Reddy et al., 2015; Tayan, 2017). Therefore, measuring students' understanding of scientific concepts and their misconceptions in science could be one way to improve their outcomes. Another way is to study teachers' teaching behaviour when presenting new concepts to students. Additional important research avenues include exploring the impact of language barriers and terminology on learning science and investigating the role of physics textbooks in promoting student misconceptions. Hence, this study aims to uncover these important issues regarding physics learning and education.

The current study focused on two groups: 742 Saudi female students who are in Year 11 at five different schools and 30 female physics teachers. The study used two sources of data to identify Saudi physics teachers' and students' alternative thermal conceptions. The first was the Thermal Concept Evaluation (TCE) instrument designed by Yeo and Zadnik (2001) to investigate students' alternative conceptions regarding thermal physics concepts (see Chapter 6, Sections 6.2–6.3). The second source of information was a workshop designed to help teachers overcome their own misconceptions in order to change the old schema their students have embraced regarding thermal physics (see Chapter 6, Section 6.4).

As mentioned previously, the quality of the Saudi education system has become more and more exposed to the world due to international assessments (i.e. TIMSS, PIRLS, and PISA). Hence, this study may help enlighten Saudi physics teachers on how students learn new scientific concepts (e.g. thermal concepts) and the difficulties they face by introducing the three scenarios of the conceptual change approach—assimilation, equilibration, and accommodation—as explained by Posner et al. (1982). In addition, the study examines how misconceptions develop that are not in line with modern scientific theories, as explained by Gooding and Metz (2011), as well as what triggers conceptual changes to occur, as explained by Duit, Treagust, and Widodo (2008). Finally, this study highlights teaching behaviour amongst Saudi female physics teachers in order to understand how they pass on the new physics concepts to their students.

In terms of research, very few studies have concentrated on the Saudi Arabian educational system for female students and fewer still have been conducted by female researchers. For example, the two largest research centres in Saudi Arabia, King Abdullah University of Science and Technology and King Abdulaziz City for Science and Technology, do not list research in education as part of their interests on their respective websites. The current study seeks to expand research in this field in Saudi Arabia by focusing on the education of female students and investigating Saudi female students' level of understanding of thermal concepts and the types of alternative concepts they hold.

1.3 Theoretical Framework

Definitions of physics concepts, such as heat and temperature, are abstract, and misconceptions often interfere with these definitions that are then developed and handed down over generations through everyday language (Chi, 2008; Sözbilir, 2003). Evidence from the literature also shows that misconceptions regarding heat and temperature are not limited to one nation or another (Nawafleh, Banikhalaf, & Al-Momani, 2016). Such misconceptions are blamed for inhibiting meaningful learning of these concepts (Saricayir, Ay, Comek, Cansiz, & Uce, 2016).

According to Gooding and Metz (2011), every person has his or her own misconceptions that occur due to the need to understand different phenomena, and these misconceptions become entrenched when they remain unchallenged. On the other hand, for many decades and over multiple disciplines, particularly in learning science, the conceptual change approach has been recognised as an effective strategy to challenge students' misconceptions in terms of learning and teaching science (Duit & Treagust, 2003). It is well known that some physics concepts, such as thermal concepts, are very challenging for students to understand due to the gap between the scientific definitions and the vernacular terminology for heat, temperature, and energy (Brookes & Etkina, 2015; Clough & Driver, 1985; Erickson & Tiberghien, 1985; Kesidou, Duit, & Glynn, 1995). Indeed, students come upon the terms 'heat', 'temperature', and 'energy' in their everyday lives. Consequently, students believe they have a correct understanding of such scientific terms (Harrison, Grayson, & Treagust, 1999). However, the vernacular definitions significantly vary from those used in science (Carey, 1992; Vosniadou, 1994; Wiser & Carey, 2014). For instance, according to Hewitt (2006), *temperature* is a measure of the average kinetic energy of molecules or atoms. *Heat* is used by scientists to indicate energy flow due to temperature differences and is an energy process, not the storage of energy (Kesidou et al., 1995). When there is a difference in temperature between bodies in contact, heat flows from the body with the higher temperature to the body with the lower temperature (Hewitt, 2006). After heat has been transferred to an object or substance, the object ceases to be heated and becomes internal energy (Hewitt, 2006).

However, previous research has found that the majority of students believe bodies contain heat (i.e. heat can be contained) (Chi, 2013). In addition, many students consider heat to be an *intensive quantity* that does not depend on object size, and they consider temperature to be the amount of heat (i.e. heat and temperature are the same thing) (Kesidou & Duit, 1993; Yeo & Zadnik, 2001). After they have learned new thermal concepts in Year 11 (i.e. the concept of specific heat capacity), students adjust their interpretation of thermal phenomena around them by using the new specific heat capacity concept, which they also use to explain thermal equilibrium. Consequently, students start to consider heat partly as an *extensive quantity* that depends on the amount of substance in the objects (Vosniadou, 1994). Many students use the concept of specific heat capacity loosely to explain the efficacy of heat conduction or the ease of thermal equilibrium to be reached without considering the rate of temperature change or the amount of heat energy transfer (Chiou & Anderson, 2010; Harrison et al., 1999)

Students' misconceptions, however, are not isolated from their teachers' practise and teaching behaviour, which strengthens the claim that teachers are the most important factor in the educational process (Duffee & Aikenhead, 1992). In their explanation of how people experience cognitive growth, Bereiter and Scardamalia (1993) defined the phenomenon of 'knowledge concentration' as the way people become more comfortable with the knowledge they have and increasingly '"feel more at home" in an area that becomes smaller' (as cited in van Driel, Beijaard, & Verloop, 2001, p. 141). Accordingly, teachers are less likely to challenge or update their own knowledge because, from their point of view, it works, and there is no need to change it. The practical knowledge of teachers is a mixture of their experiential knowledge, formal knowledge, and personal beliefs (van Driel et al., 2001). Teachers tend to recycle and accommodate their old thoughts and information even when implementing the most innovative teaching strategies; this also occurs with retaining misconceptions. Thus, these misconceptions are handed from teachers to students and from one generation to another.

1.4 Purpose of the Study

The general purpose of this study is to evaluate how a sample of Saudi female high school students and their physics teachers understand thermal concepts. The study has four specific purposes: (1) to identify the thermal concepts that are understood scientifically by Saudi female students before and after instruction, (2) to investigate whether or not well-documented misconceptions related to thermal concepts are prevalent amongst the study participants before and after thermal energy instruction, (3) to identify the level of understanding regarding thermal energy scientific concepts exhibited by Saudi female teachers, and (4) to investigate the possible sources of Saudi students' and teachers' misconceptions regarding thermal physics. This study took place in the Eastern Province of Saudi Arabia.

1.5 Research Questions

The following primary research question was pursued in this work: What is the level of thermal energy concepts understanding exhibited by Year 11 Saudi female students and their teachers in the Eastern Province of Saudi Arabia? To further illuminate this issue, the following sub-questions were addressed:

1. What thermal concepts are understood scientifically by Saudi female high school students before and after instruction?
2. What misconceptions are formed by Saudi female high school students about thermal energy before and after thermal energy instruction?
3. What is the level of thermal conceptual understanding exhibited by Saudi female high school teachers?
4. What are the possible sources of Saudi female high school students' misconceptions regarding thermal physics?

Table 1.1 illustrates how the main research question and sub-questions served the purposes of the study, including framing the study with assumptions that were either confirmed or nullified, and in which chapters these questions are answered.

Table 1.1 *Main Research Questions purposes and pre-assumptions*

Purposes	Research Question	Pre-assumptions	Chapter
▪Investigate how the thermal concepts are understood scientifically by Saudi female students before the instruction.	1. What thermal concepts are understood scientifically by Saudi female high school students before and after instruction?	Thermal physics concepts are significantly understood by Saudi female students before instruction.	Chapter 6
▪Investigate the misconceptions formed by Saudi female high school students about thermal energy before and after thermal energy instruction.	2. What misconceptions are formed by Saudi female high school students about thermal energy before and after thermal energy instruction?	A significant difference exists between students' misconceptions about thermal physics before and after instruction.	Chapter 6
▪Investigate the level of thermal conceptual understanding exhibited by Saudi female teachers in the Eastern Province of Saudi Arabia.	3. What is the level of thermal conceptual understanding exhibited by Saudi female high school teachers?	Saudi female teachers exhibit a satisfactory level of understanding of thermal physics concepts.	Chapter 6
▪Identify the possible sources of Saudi female students'/teachers' misconceptions regarding thermal physics (e.g. textbooks).	4. What are the possible sources of Saudi female high school students' misconceptions regarding thermal physics?	Teachers are the main source of students' misconceptions regarding thermal physics.	Chapter 7
▪Investigate the level of thermal energy overall understanding exhibited by Year 11 Saudi female students in the Eastern Province of Saudi Arabia.	(Main) What is the level of thermal energy concepts understanding exhibited by Year 11 Saudi female students and their teachers in the Eastern Province of Saudi Arabia?	Saudi female students show a satisfactory level of understanding of thermal physics concepts.	Chapter 8

1.6 Significance

Many studies from around the world have investigated students' misconceptions in almost every scientific topic. The significance of the study is also evidenced by the useful insights provided for future research related to Saudi education for female students. This is especially evident from the modernisation of the Saudi educational system for females through the identification of factors that drive incorrect responses to misconception diagnostic tests established in developed countries and based on Western standards.

1.7 Research Design

A mixed methods research design was developed to answer the research questions of this study (see Chapter 5, Section 5.1). As defined by Johnson, Onwuegbuzie, and Turner (2007), the purpose of the mixed methods design is to acquire different but complementary information to explain the same phenomena dealt with in the research and to provide the best understanding of the research problem. According to Creswell and Clark (2017), a mixed methods research design can help overcome the weakness of each method when used individually (Johnson et al., 2007). In a mixed methods design, researchers are more likely to provide more evidence about the research problem (Creswell & Clark, 2017) and are more flexible regarding the use of varied research tools. Furthermore, a mixed methods design helps in answering questions that cannot be answered fully using only one of the two methods, such as whether the data sets obtained from the qualitative and quantitative data are convergent or divergent (Creswell & Clark, 2017). To enhance the research findings, a triangulation method was used. Denzin (2017) defined triangulation as a 'combination of methodologies in the study of the same phenomenon' (p. 291) and distinguished the two methods as within-methods triangulation and between-methods triangulation. Thus, this research study used the latter method, which referred to using both quantitative and qualitative approaches (Johnson et al., 2007).

1.8 Organization of the Thesis

The thesis consists of eight chapters, as shown in Figure 1.1. Chapter 1 provides an overview of the thesis, the research design of the study, and the framework of the conceptual change approach. The chapter also discusses the rationale for the study to the research body, its significance, and its purpose. Finally, the chapter identifies the main research question as well as the four research sub-questions.

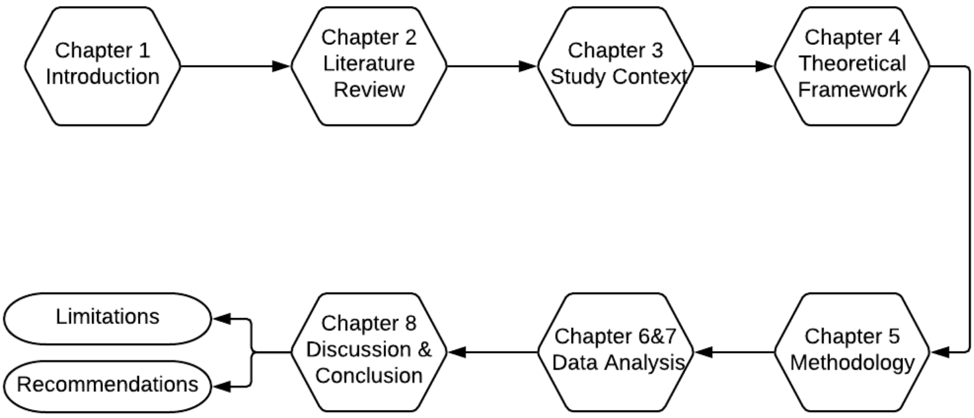

Figure 1.1 Overview of the thesis

Chapter 2 reviews all relevant literature from Saudi Arabia and around the world regarding students' misconceptions in general and regarding thermal physics in particular. Special attention is paid to the sources of students' misconceptions as reported by researchers in the literature. Moreover, Chapter 3 covers the study context, including some history background of female education in Saudi Arabia and its missing philosophy knowledge. In addition, Chapter 4 illustrates the framework that underlies the research, such as the conceptual change approach by Vosniadou (2013), Posner et al. (1982), and Duit et al. (2008); the Mental Models (MM) framework by Chi (2013) and its explanation of robust misconceptions in science; and teachers' practical knowledge and teaching behaviour by van Driel et al. (2001).

Chapter 5 discusses the research methodology and data collection as well as data analyses. This chapter also outlines the planned research strategy for collecting the data and describes the research participants' demography. Moreover, Chapter 6 presents the data analysis aimed at illuminating Research Questions 1, 2, and 3 (regarding the scientific and non-scientific beliefs Saudi female students and their teachers have about thermal energy) by using the conceptual change approach and the mental models as a gauge to interpret the responses of both students and their teachers.

Chapter 7 presents the data analysis intended to elucidate Research Question 4 regarding Saudi students' misconception sources by analysing textbook content and terminology. Finally, Chapter 8 summarises the research findings obtained from the data analyses and matches those findings with the research questions. The conclusions, recommendations, and limitations of the research are also discussed in this chapter.

1.9 Terminologies and Definitions

The terminologies and definitions used in this work are as follows:

- **Prior knowledge:** This refers to all types of cognitive frames that students bring to the learning process, encompassing knowledge, skills, and abilities prior to instruction (Dochy, Segers, & Buehl, 1999).
- **McGraw-Hill textbooks:** These are the only official textbooks used in high school and other educational levels in Saudi Arabia.

- **Misconceptions:** Synthetic mental models that produced when the new information is added to the incompatible knowledge base, and effectually become underlying source of error (Fisher & Lipson, 1986; Vosniadou & Verschaffel, 2004).
- **Alternative conceptions:** These refer to a person's naïve explanations constructed during the instructions in classroom, in order to understand, explain, or predict events that they come across in their daily life (Berg & Brouwer, 1991).
- **Non-existent mental model:** Sometimes called the missing mental model, this is caused by the absence of prior knowledge regarding concepts that are to be learned (Chi, 2008).
- **Conceptual change:** Teaching and learning approach that used when the To-be-learned information (new schema) is in conflict with the exist information (old schema) (Vosniadou & Verschaffel, 2004).
- **Scientific concepts:** These concepts are definitions and explanations provided by different field experts from developed countries (Fleer, 1999).

1.10 Summary

This chapter provided a reference to navigate through the research study by introducing and shedding some light on its different elements. In Chapter 2, various works from the literature are reviewed regarding students' misconceptions and possible sources of those misconceptions from different disciplines.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter defines the underlying concepts associated with the research questions to provide insights into the analysis and interpretation of the results, along with a comprehensive overview and analysis of the relevant literature linked to the study topic. The studies covered in the review are on science misconceptions in general (Section 2.2). Students' science and thermal physics misconceptions are discussed in Section 2.3 and Section 2.4, respectively. Previous studies that used the TCE instrument are reviewed in Section 2.5, and possible sources of students' misconceptions are reviewed in Section 2.6. The main research question is as follows: What is the level of thermal energy concepts understanding exhibited by Year 11 Saudi female students and their teachers in the Eastern Province of Saudi Arabia?

2.2 Historical Overview of Students' Misconceptions

Shedding light on the issue of students' misconceptions necessitates a review of the history of the word 'misconception'. The era between the 17th and 19th centuries witnessed a massive interest in people's beliefs, which were described during that time as superstitions (Caldwell & Lundeen, 1931; Emme, 1940). This interest was reflected in the huge volume of publications about the superstitions held by students, teachers, adults, and experts. Two of these early publications were those of University of Pennsylvania. Society of the Alumni (1729) and Campbell, Pendleton, and Loos (1731). This interest declined dramatically in the mid-18th century. At that time, there was a noticeable confusion regarding the terms 'superstition' and 'misconception'—a confusion that was not restricted to ordinary people but extended to educators and psychologists. Garrett and Fisher (1926) and Levitt (1952), for example, used these terms interchangeably in their studies, which is not surprising considering how difficult it was to distinguish between most of the misconception synonyms that had been used in that era (Vosniadou, 2013).

By the 20th century, the predilection towards treating beliefs as superstitions began to diminish, with many scholars drawing boundaries to differentiate superstitions from misconceptions. One of the earliest attempts in this regard was extended by Moody (1912), who described misconceptions as vague notions. Another was the work of Hancock (1940), who defined a misconception as an ‘unfounded belief that does not embody that element of fear, good luck, faith or supernatural intervention’ (p. 208). Differentiating between superstition and misconception was not limited to delineating boundaries but also involved increased self-consciousness among experts and educators about science misconceptions in general and thermal energy misconceptions in particular (Stodola & Loewenstein, 1927).

In the early part of the 20th century, a heavy emphasis was placed on differentiating misconceptions about science from known superstitions. Hancock’s (1940) study evaluated certain popular science misconceptions among 53 experienced teachers from 25 U.S. states in terms of how these misconceptions affect behaviour and differentiate unfounded beliefs from superstitions by saying that unfounded beliefs (i.e. misconceptions) is based on some scientific evidence, rationalisation, or a cause-and-effect relationship. He went on to state that unfounded beliefs generally tend to be harmless. Conversely, superstitions are devoid of any rational justification, in addition to causing potential harm. The author noted that superstitions usually include an element of fear, are linked to either good or bad luck, or involve ‘faith or supernatural intervention’ (Hancock, 1940). In contrast to superstitions, misconceptions usually resulted from sloppy observation, lack of support for established facts, or incorrect interpretation (Hancock, 1940). The author also pointed to existing evidence regarding the guidance of unfounded beliefs over a person’s acts in everyday life and remarked that even though some misconceptions are harmless, others may cause unnecessary difficulties for individuals and affect believers’ behaviours.

The past 50 years have seen increasing endeavours by researchers to distinguish among a preconception, prior knowledge, misreading, and misconception. Driver and Easley (1978) distinguished students’ misconceptions from alternative conceptions by delineating the former as misunderstandings or ‘wrong ideas’ developed by students who have been exposed to and have erroneously assimilated formal models or theories. Conversely, alternative conceptions are frameworks autonomously developed by students to conceptualise their experience of everyday phenomena (Driver & Easley, 1978). Chi (2008) added that alternative conceptions are incomplete prior ideas used by students to address gaps in their learning, whereas misconceptions are prior ideas that conflict with precise scientific concepts. Madu and Orji (2015) defined misconceptions that are persistent and resistant to change as ‘robust misconceptions’ (p. 2). Kácovský (2015) explained that misconceptions constitute prior knowledge that is consistent with scientific theories, whereas alternative conceptions make up prior knowledge that is inconsistent with scientific theories. And, more recent, common sense, vernacular, non-scientific, content-based, and nature of science-based misconceptions have been differentiated even further (Yeh, Huang, & Yu, 2017).

The history of misconceptions has also been characterised by increasing emphasis on the need to delve deeper into students' ideas, with philosophers and experts stating that not all students' misconceptions are wrong (Clement, Brown, & Zietsman, 1989; Goldberg & McDermott, 1983). Klopfer, Champagne, and Gunstone (1983) asserted, however, that such faulty impressions are remarkably resistant to change. Similar views were presented by Eaton, Anderson, and Smith (1984), who explained that student misconceptions are stable and firmly embedded in their minds, resistant to correction via instruction and therefore difficult to correct or eliminate. Even innovative instructional intervention has generally failed to improve student understanding (Richard, 1998). Jara-Guerrero (1993) indicated that misconceptions are not just simple mistakes but tend to be stable, well-structured, and intractable ideas. The author added that because misconceptions are deeply rooted and are a product of common-sense theories, ordinary instruction has a minimal effect on them. Confrey (1990) agreed with the aforementioned researchers, stating that changing students' misconceptions is difficult. This historical development of distinguishing between Superstition; Misconception; and alternative conceptions is illustrates in Figure 2.1.

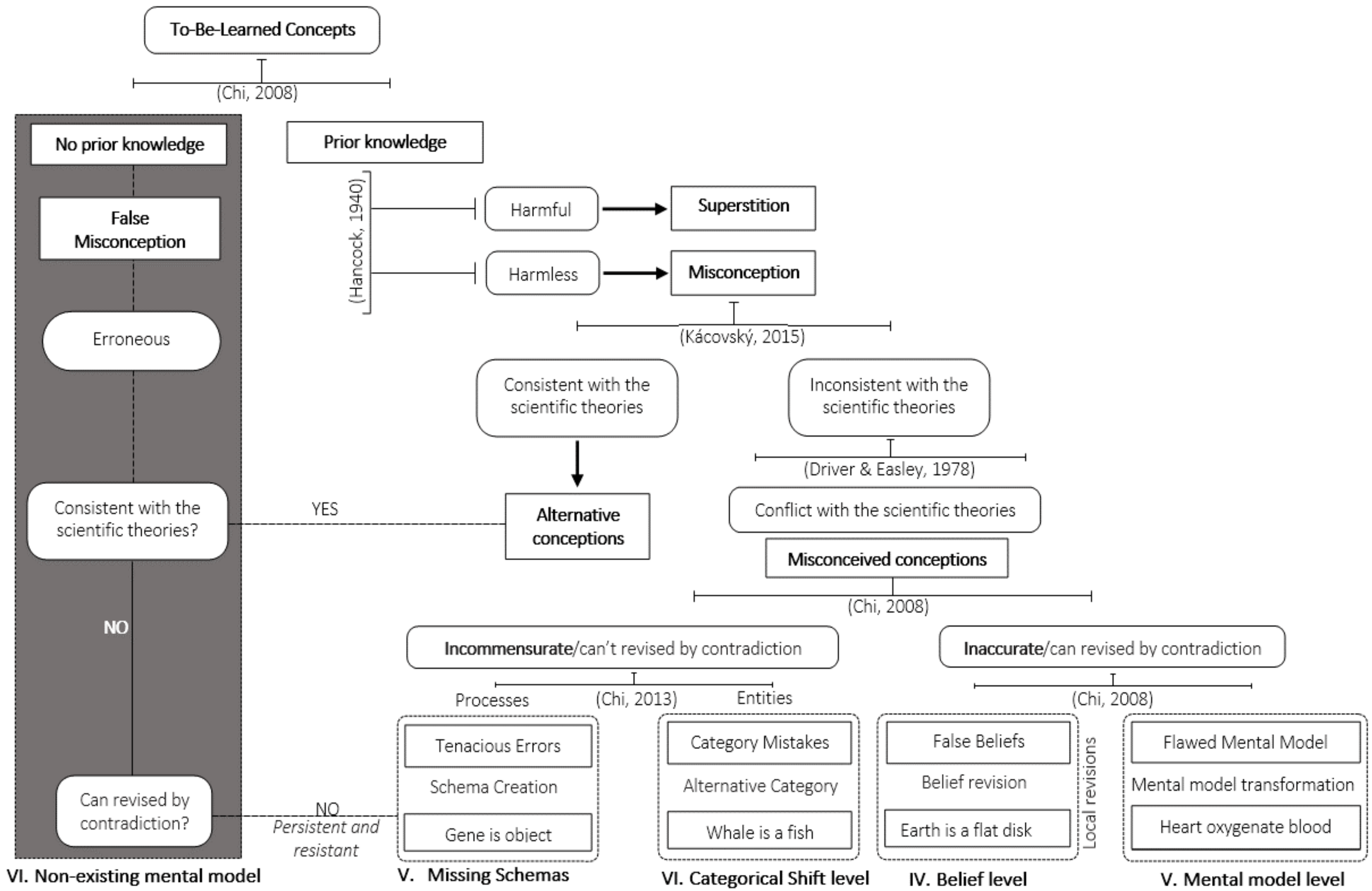

Figure 2.1 The historical development of distinguishing between Superstition; Misconception; and alternative conceptions

2.3 Students' Science Misconceptions

An early investigation conducted by Ralya and Ralya (1938) probed into whether the current system of teacher training at a South Carolina state college adequately prepared pre-service teachers to teach science topics in elementary schools. The study also explored common misconceptions and superstitions among pre-service teachers. To these ends, the authors used a questionnaire with 240 true/false items containing six themes. These findings indicated a prevalence of science misconceptions among prospective teachers, out of whom, 59% also believed in harmful folk superstitions. In addition, 85% of the respondents lacked knowledge and understanding of science and held misconceptions regarding its most basic principles.

Less than 15 years later, Blanchet (1952) conducted a cross-cultural study to look into the 100 most important misconceptions likely to affect individuals' behaviours that were previously highlighted by Hancock (1940). Blanchet investigated the prevalence of Hancock's science misconceptions among 318 in-service African American teachers who had either completed their bachelor's degrees or completed anywhere from one to 11 quarters of their college work at Fort Valley State College in Georgia (also known as Fort Valley State University). Blanchet asked the teachers to underscore the words and/or phrases that they did not understand when they did not give either a true or false answer on a test. Almost one-third of the participants did not answer one or more questions because they did not know one or more words on the test. These words or phrases, which are linked to everyday experiences, included the following: osteopath, chiropractor, masturbation, oculist, optometrist, alkali, Ovaltine, malnourished, gonorrhoea, feeble-mindedness, ailments, hydrogen peroxide, colour blindness, venereal, and others.

Further investigations into individuals' science misconceptions were initiated in the 1970s, during which researchers explored elementary school students' misconceptions. Doran's (1972) longitudinal study was aimed at examining students' understanding of science concepts, with particular focus on elementary school students' misconceptions related to the particle theory of matter and their mathematical skills, reading skills, science skills, and IQ scores. The author's technique involved grouping a list of eight misconception statements into subtests on the basis of the misconceptions represented by item distractors to learn what students may not have accomplished and why not. The author used a quantitative method to gather data from 253 White, middle-class students in Year 2–6 from a public school in Wisconsin. The study found no correlation between test scores and mathematical ability, reading ability, or IQ score. However, a slight positive correlation was found between test scores and science ability. The author concluded that dividing misconception items into subtests on the basis of misconceptions denoted by item distractors is considerably more reliable than conventional misconception tests.

A new stream of research on students' understanding of science concepts stemmed from the work of Samuda (1973), who criticised cross-cultural studies for being based on a non-valid comparison between bilingual students with low socio-economic backgrounds and monolingual English-speaking students with middle and upper socio-economic backgrounds. He added that such studies lack a reasonable conclusion as to whether these differences are related to language and/or cultural factors or are due to socio-economic status. He offered an example of all circumstances involved in teaching and the evaluation of Black ghetto students, emphasising that studies based on teaching of children with different cultural backgrounds is inappropriate either in how they teach or how they evaluate these students' understanding.

Mali and Howe (1979) performed a cross-cultural study to inquire into Nepalese students' misconceptions regarding the earth and gravity, with a view to determining whether American children's misconceptions about the earth are evident in Nepalese culture. In a valley lying at the foot of the Himalayas, 250 students aged 8, 10, and 12 and studying in Year 1–7 were interviewed with the assistance of objects and diagrams. The authors found that Nepalese students have limited access (or none at all) to Western scientific world views for historical and geographical reasons, including high illiteracy among adults, an agricultural living background, and a shortage of media and informal programs about the earth.

Ordinary Nepalese individuals believed that the earth is flat, with four corners supported by an enormous elephant. The students were found to hold many misconceptions regarding the earth and gravity, with some similar to those reported in Nussbaum and Novak (1976) work on American and Israeli students. The other misconceptions may be limited to the context of Nepal. Mali and Howe (1979) also discovered that some concepts, such as the earth and its gravity, are non-existent in the Nepalese students' intellectual environment. Thus, the students were unaware of the earth's correct shape; many thought of it as a large disk with no space below it. The authors concluded that changing Nepalese students' misconceptions would be more difficult and more time-consuming than modifying those of American students.

Due to the lack of research regarding students' misconceptions on science in South Africa, Helm (1980) conducted a study involving 334 students from five 'White' schools that use English as a medium of instruction, 126 first-year physics majors at Rhodes University, and 65 teachers at the Cape Education Department in the Eastern Cape Province of South Africa. Using one-tier, multiple-choice questions with four distractor answers to represent common or suspected misconceptions, the author investigated the students' physics misconceptions regarding centripetal force, potential difference, quantitative electrostatics, oscilloscope signals, and Hooke's law. Some of the misconceptions, such as those related to oscilloscope signals, may be restricted to the South African context because of terminology issues.

No difference in test performance was found between the school students and university students. In 70% of the test questions, only a small percentage of the respondents were able to choose the correct answers. In nearly all the questions, certain alternative conceptions were repeated by all the groups, including the teachers. The teachers, for example, did not show better understanding than the students is explain why matter releases energy in nuclear fission. In general, the teachers provided a slightly higher number of correct answers than did the students, but this level of correct responses did not exceed 80%. Helm (1980) ascribed his respondents' misconceptions to teachers, textbooks, and ill-conceived examination papers. Helm also found that every educational level used a limited number of textbooks, which teachers relied on heavily and which appeared to be full of misconceptions, errors, and omissions. Helm discovered that university textbook authors acquired their knowledge from previously developed university examination papers that featured misconceptions, thus rendering the examinations the standard of correctness for the textbooks instead of the other way around. Helm concluded that even when misconception sources are identified, correcting textbooks and examination papers and educating instructors would not guarantee the elimination of misconceptions for future generations because of the mismatch between African students' intellectual development and what they study in schools (which are unfamiliar to them). In the author's opinion, the matter required not only the ‘accuracy of exposition of the spoken and printed word but also careful attention to the educational context’ (Helm (1980, p. 97).

Following the Helm (1980) study, Ivowi (1984) explored Nigerian high school students’ misconceptions regarding physics concepts, such as waves, fields, quanta, and conservation principles. The author used a test with 20 multiple-choice items and five alternatives for inquiring into students’ misconceptions, with 12 out of the 20 questions quoted and modified from Helm (1980) work. The test was administered to students aged 15–17 years and studying in eight high schools (four federal schools and four state schools). No correlation was found between school type (federal/state) and students’ misconceptions. The studies of Ivowi (1984) and Helm (1980) are similar in terms of low performance, but note that high school students’ misconceptions differ from those of university students. The results of Ivowi also indicated that the teachers shared their students’ misconceptions, confirming that the latter can stem from the former, as similarly verified by Helm (1980). Ivowi blamed the curriculum, inadequate facilities, and the shortage of experienced physics teachers as the reasons for the Nigerian students’ misconceptions. He additionally declared that teaching methods based on ‘talk and chalk’ (1984, p. 279), which encourage memorisation, abstract concepts, textbook use, evaluations, and large classroom populations, create an environment that is conducive to the spread of misconceptions among Nigerian high school students.

In another study, Western Australian students in Year 11–13 were examined for their misconceptions of chemistry by Treagust (1988), who designed an instrument consisting of a two-tier (answer/reason) multiple-choice test. The instrument is considered one of the easiest ways to uncover students’ misconceptions. The study highlighted that it can be difficult to recognise student misconceptions given that such misconceptions are usually embedded firmly in students' cognitive structures. Nevertheless, knowing and measuring students' misconceptions is important for providing teachers with a point of departure for delivering lessons.

Based on Samuda's (1973) criticisms of cross-cultural studies, Klein (1982) conducted a cross-cultural study (after controlling for socio-economic factors) that involved 12 Mexican American (bilingual) children and 12 Anglo-American children aged 7 and 8 studying in Grade 2 classes at a St. Paul, Minnesota, public school. The research was aimed at examining the students' understanding of eight concepts regarding the earth and sun. It also explored differences in terms of explanations given regarding the aforementioned concepts and differences in developmental patterns between the two races. The study revealed many different ideas held by the students and indicated that although the majority of the students in both cultural groups lacked an understanding of most earth and sun concepts, a number of answers based on pre-causal thinking were given by the Mexican American children, who gave fewer correct responses than did the Anglo-American students (Klein (1982). The most difficult concepts were about the earth in space, the notion of perspective, the cause of night and day, and the reason for sunrise times being different in various geographical locations. The study likewise found consistency in the pre-causal thinking of the students, and the interview results suggested that language plays a vital role in learning for bilingual students—a role that may not be obvious to teachers. The author suggested that further investigation is needed to determine whether or not students' low understanding is a result of either the overly abstract nature of the concepts or language difficulties, especially among children for whom English is a second language.

On the other hand, formal research on students' ideas took longer to initiate in Arabian countries. In 1975, cross-cultural and cross-age studies by Za'rour were aimed at identifying erroneous ideas and exploring the prevalence of science misconceptions among 1,444 local participants from 11 high schools. Specifically, the studies involved freshmen, juniors (Lebanese with random socio-economic statuses), and all sophomores from the American University of Beirut[1] and 130 American students from the American Community School in Beirut, where science is taught in the English language. The purpose of the studies was to determine the relationship between students' erroneous ideas and certain variables, such as years of education, gender, science major, science achievement score, and culture. The final copy of the test consisted of 40 multiple-choice questions that featured 108 misconceptions regarding science, with each question having four alternatives. Half of the questions concentrated on physics misconceptions. The multiple-choice questions were directed towards determining whether any alternative conceptions were more popular among the students than others.

Za'rour (1975) found that misconceptions were prevalent among 68% of the sample and that neither cross-age nor cross-gender differences in performance existed between Year 9/Year 11 students and the university students. Some of the percentages related to misconception occurrence were either near or below the level of chance, especially among the local Lebanese students. The author also found that some statements, such as that on oxygen being the most common gas in air, were highly misinterpreted by the American students but not by the locals. Za'rour attributed the American students' misconceptions to language discrepancies and ascribed the local students' correct

[1] The author, however, did not mention the percentage of those students.

answers to the fact that local students tend to memorise data about the percentages of gases in air. Almost half of the Year 9/Year 11 students and university students believed that the temperature of the iron component of a chair is greater than the temperature of the wooden component. More than 40% of the Year 9/Year 11 students and more than 30% of the university students were of the opinion that increasing the heat supply to boiling water increases its temperature. Factors such as socio-economic aspects, teaching methods, and curricula were suspected as potential drivers of the development of science misconceptions among the students.

A cross-age study on students' initial common-sense knowledge about physical phenomena, mathematical skills, and academic achievement scores was conducted by Halloun and Hestenes (1985). The authors administered the multiple-choice Mechanics Diagnostic Test to 1,500 students at Arizona State University in the United States and 80 high school students from Arizona State local schools with high academic achievement. The high school students earned extremely low scores on a pre-test, and their scores were slightly above chance-level scores on the Mechanics Diagnostic Test. A similarly low performance was exhibited by the university students. The initial pre-test results revealed a seriously defective conceptual vocabulary among the students, and the post-test results showed no correlation between student performance in introductory physics and gender, academic major, or mathematical skill. The researchers concluded that with such low results, the students likely misread every idea that they see and hear in physics classes. They also clarified, however, that the low test scores do not translate to the absence of knowledge regarding basic mechanics concepts; rather, the scores reflect that alternative concepts are severely rooted in the students. The researchers further explained that the danger of having alternative conceptions does not lie in the possibility of misunderstanding but in the possibility that individuals will embellish their misconceptions in a scientific manner and carry a false sense that they have acquired scientific knowledge. The results showed neither cross-age improvement nor a decline in students' misconceptions as they aged; the university students' low scores in the pre-test were no better than those who had studied physics for the first time. Such performance was attributed to introductory physics courses, which the researchers claimed were characterised by incomprehensibility and instructional failure. Nevertheless, Halloun and Hestenes noted that instructors cannot be blamed for such failures if they do not know about students' misconceptions or how to change them. They stated that knowing about such misconceptions leads to their incidental treatment.

Via an examination strategy oriented towards higher-order cognitive skills (HOCS), Zoller (1996) made distinctions between misconceptions, misunderstandings, and no conceptions among college students studying chemistry. The study involved 11 male and 39 female Jewish and Arab students (ratio 4:1) who were science majors at the University of Haifa. Among the study population, 80% were prospective secondary school biology teachers, and 20% were prospective physics and mathematics teachers. Zoller designed the HOCS-oriented examination strategy to reveal students' misconceptions and shift their thinking from lower-order cognitive skills to HOCS. The study aimed to encourage 'guided, independent non-test-driven self-study' (1996, p. 319), and, to access quick feedback, the author conducted a pre-test, HOCS instructions activities, a post-test, and interviews with students found to have at least one of the misconception types examined. Under the no conceptions category, the students' answers failed to mention certain necessary concepts, such as resonance stabilisation and aromaticity. They also failed to provide any relevant, reasonable, or consistent explanations about a question related to the mononitration of α-naphthol and indicated no guarantee that they could establish a connection between or apply what they had learned to new situations. In the misconceptions category, the students provided clear-cut misconceptions about specific core scientific concepts. In the misunderstandings category, the students may have understood and correctly conceptualised the core concepts, but they misunderstood the mathematical implications of highly basic and highly acidic solutions. Zoller noted that revealing students' misconceptions and their subcategories is insufficient if teaching and learning strategies continue to adhere to traditional paths; each misconception type must be treated differently.

Zoller's (1996) strategy for differentiating between the three levels of students' errors was also used by Al-Rashed (2002) to investigate scientific misconceptions among 246 male pre-service teachers majoring in science at a teachers college in Riyadh, Saudi Arabia. Al-Rashed placed students' errors in science into four categories: (a) errors caused by no prior knowledge of a concept, (b) errors caused by little prior knowledge of a concept, (c) errors resulting from faulty knowledge (misconceptions), and (d) suspected errors that may be considered wrong concepts. The author concentrated on the third type of error (misconceptions) because Al-Rashed considered the first two to be standard errors that are easily corrected. He adopted a two-tier (answer/certainty), multiple-choice questionnaire comprising 29 questions taken from Lawrenz (1981), Perz and Carrascosa (1990), Trembath (1990), and Phillips (1991). Al-Rashed (2002) used a t-test to differentiate between misconceptions, which he described as dangerous ideas and normal errors. The coefficient of the students' certainty regarding *correct* answers could be either statistically significantly higher or not statistically significantly higher than the coefficient of the students' certainty regarding *incorrect* answers. If the coefficient of certainty for correct answers was found to be statistically significantly higher than the coefficient of certainty for incorrect answers, then the students were evaluated as displaying definitive, correct knowledge (Case 1); if the opposite was found, then the students were assessed as having little knowledge of a concept (Case 2). Similarly, the coefficient of students' certainty for *incorrect* answers could be either statistically significantly higher or not statistically significantly higher than the coefficient of their certainty for *correct* answers. If the former was found to be true, then the students were identified as having misconceptions (Case 3), and if the latter was applicable, then the students were indicated as having suspicious misconceptions (Case 4). With this strategy, Al-Rashed found that the pre-service teachers exhibited an almost full understanding of 15 of the 29 scientific concepts. The participants exhibited partial understanding of seven scientific concepts; the respondents held definite misconceptions about two of the concepts and suspicious misconceptions about five of the concepts. The two definite misconceptions were those related to gravitational interactions of the earth and moon and the ratio between water components. Al-Rashed attributed the misconceptions to science textbooks that are full of ambiguous statements and the focus on mathematical problem solving instead of conceptual understanding.

Al-ghaleeth (2008) delved into the alternative physics conceptions and attitudes towards studying physics among Palestinian Year 11 students (100 males and 100 females) from four schools in Gaza City. The author developed a 30-item, two-tier (answer/explanation), multiple-choice questionnaire, in which a maximum of 60 points could be earned. The researcher registered 13 misconceptions held by the study's sample. The most prevalent alternative concept was 'electric field = field strength × vertical surface area' (2008, p. 82), with a rate of prevalence above 60%. The study suggested that the low performance of the Year 11 students stems from the lack of access to correct information, the lack of linkage between previous and current experiences, low academic achievement, the lack of advanced thinking skills, and an environment that prevents experimentation given the unstable safety situation in the Gaza area. Al-ghaleeth stated that such misconceptions may affect the motivation of students to learn science, cause students to withdraw from the learning process, and affect their ability to apply knowledge to new situations and experiences. She recommended investigating teachers' misconceptions using the same tool used to determine whether teachers influence students' misconceptions, as well as exploring physics textbooks for potentially ambiguous language.

Using a questionnaire developed by Lewis, Leach, and Wood-Robinson (2000), Aldahmash and Alshaya (2012) a conducted a cross-cultural study to investigate Year 11 Saudi students' misconceptions of genetics and heredity. The questionnaire, which was divided into two sections (cells and reproduction), consists of two-tier (answer/open-ended reason), multiple-choice items and has been used successfully in the United Kingdom and India. The study focused on the percentages of wrong answers as a reflection of students' misconceptions, with any percentage over 25% regarded as indicative of a misconception. The authors noted misleading results, which showed that half of the students understood cell division when, in reality, they did not. They relied on the students' responses to the written section to justify their understanding of cell division, for which 65% lacked satisfying answers. The results of the questionnaire's first section showed that the students could not differentiate between direct and indirect division and that most of them (78%) could not distinguish between animal and plant cells. The first section of the questionnaire indicated that over half of the participants understood both sexual and asexual cell division, whereas the written section revealed that less than 25% gave correct answers. Aldahmash and

Alshaya also commented on the students' lack of skills for drawing cell diagrams. The results of the questionnaire's second section generated similar misleading results, showing that over 50% of the students understood asexual and sexual reproduction in animals and plants, whereas the written section revealed that about 30% gave correct answers. Almost all the students did not know why "an animal that could reproduce asexually would still need to reproduce sexually" (p. 12)[2]. The students were likewise unaware of how plant reproduction occurs. The authors concluded that UK students' misconceptions regarding genetics and heredity (Lewis et al., 2000) and Indian students' misconceptions (Chattopadhyay (2005) were also prevalent among Saudi high school students. The Saudi students' misconceptions regarding many questions were ascribed to their lack of understanding of genetics, the nature of the science textbook, the lack of professional teaching skills, and socio-religious factors (Aldahmash & Alshaya, 2012).

Zinedine (2016) recently investigated alternative gravity conceptions among 89 sophomore and 54 senior university students majoring in physics at four Palestinian universities (Birzeit University, Al-Najah University, Al-Quds University, and Palestine Technical University). The author developed a two-tier (answer/explanation) questionnaire with 17 multiple-choice and 16 open-ended items on the basis of tests developed by (Dostal, 2005; Feeley, 2007; Williamson & Willoughby, 2012). A written section was also included to allow students the opportunity to write freely about their thoughts regarding gravity. The results showed that more than 80% of the participants believed that a planet's gravity is affected by its atmospheric pressure, density, orbiting speed, and magnetic field strength. Additionally, almost 75% of the

[2] This was extracted verbatim from the original source.

sophomores and three out of five of the seniors believed that the absence of an atmosphere translates to the absence of gravity. Four out of five of the sophomores and seniors who studied physics as their major believed in one or more properties that affect a planet's gravity. One-third of the sophomores and almost two-thirds of the seniors were convinced of a link between planetary gravity and the existence of life on a planet. Among the sophomore and senior students, three out of five did not realise that the gravitational force between two objects is equal. Almost half of the second-year students and the fourth-year students exhibited a lack of skill in using universal gravitational law. Zinedine (2016) also found that 30% of the second-year students and 20% of the fourth-year students were of the opinion that 'if an apple dropped on the moon, it would float' (Zinedine, 2016, p. 50). The most frequent response on the questionnaire was 'there is an equation for that, but I do not remember' (p. 84). The results uncovered 11 alternative conceptions held by the participants and revealed no cross-age differences among them. The author stated that the misconceptions were due to textbook diagrams that provided misleading information (e.g. showing the sun at the centre of the universe), the lack of information sequencing across all educational levels, and poor-quality methods of evaluating students' achievement.

To sum up, early studies conducted around the world showed long-lasting misconceptions among students from different backgrounds. Economic factors, bilingualism, and monolingualism were suggested as causes of students' misconceptions. However, some misconceptions were believed to be restricted to some ethnic groups. The misconceptions appeared to be more resistant to change in some ethnic groups than others. Additionally, some concepts, such as gravity, do not exist in the intellectual environment of students in some ethnic groups. Furthermore, language, socio-religious issues, and lack of knowledge played roles in the prevalence of science misconceptions among Saudi students (Al-Rubayea, 1996; Aldahmash & Alshaya, 2012).

The next section focuses on thermal physics misconceptions, which are the central issues investigated in the current work. A brief description of the history of thermal physics is provided, and the roots of some thermal physics misconceptions throughout history are discussed to determine whether this situation has changed over time.

2.4 Studies on Thermal Physics Misconceptions

Thermal physics knowledge emerged as early as the prehistoric periods, but the development of thermodynamics concepts in particular was very slow, as evidenced by the 300-year development of the thermal conductivity concept (Alex, 1933). By contrast, thermal energy and misconceptions about it were investigated as early as the 20th century (Smith, 1905). Many researchers stated that thermal energy is 'very extensive' and difficult for students to handle in a single attempt (Chu, Tan, Loh, & Treagust, 2009).

Some of the misconception statements illustrated in Table 2.1 related to thermal energy that appeared in Yeo and Zadnik (2001) and were also presented in some works that date back to the 18th century. These statements appear to be embedded in the everyday language of Western countries. An example is the statement, 'if more heat is applied to boiling water, the temperature goes higher', which was identified by Hancock (1940) as one of the 100 most popular science misconceptions that can affect individuals' behaviours. The statement continues to be used 75 years after Hancock's paper was published. Ralya and Ralya (1938) identified the statement, 'there is more heat in a barrel of warm water than in a cup of boiling water' (p. 246) as one of the misconceptions that prospective elementary teachers harboured. A similar phrase ('the temperature of an object depends on its size') appeared in the works of Yeo and Zadnik (2001, p. 498) 63 years later. Raths (1938) listed the following statement as a possible misconception: 'Would a bottle of milk, wrapped in a wet towel and placed where the air was circulating, stay sweet as long as a similar bottle of milk without a wet towel?' (p. 90). The statement still confuses students nearly eight decades after the publication of Raths's paper where it's appeared again in Yeo and Zadnik's (2001) work. Surprisingly, Barnett (2011) considered the statement 'heat rises' (p. 151) as a fact in their recently published book when many studies have regarded it as a misconception.

Table 2.1 *Some Alternative Conceptions Statements Dating Back to the 18th Century*

Yeo and Zadnik (2001) statement	Authors	Year	Page no.	The authors' statement
Heat rises.	Collins (1717)	1717	82	Heat rises.
	Barnett (2011)	2011	151	Heat rises.
Heat is a substance.	Crawford (1779)	1779	115	Whether heat be a substance or a quality.
	Smollett (1783)	1783	266	Heat (that substance which is so indispensably necessary to all living creatures).
	Nicholson (1790)	1790	6	Heat is a substance.
	Count Benjamin (1799)	1799	179	Heat is a substance.
The temperature of an object depends on its size.	Ralya and Ralya (1938)	1938	246	There is more heat in a barrel of warm water than in a cup of boiling water.
Objects of different temperature that are in contact with each other or in contact with air at different temperature do not necessarily move toward the same temperature.	Raths (1938)	1938	90	Would a bottle of milk, wrapped in a wet towel and placed where the air was circulating, stay sweet as long as a similar bottle of milk without a wet towel?
Heating always results in an increase in temperature.	Hancock (1940)	1940	212	If more heat is applied to boiling water, the temperature goes higher.
Heat and temperature are the same.	Fuchs (1987)	1987	328	Heat and temperature are the same.

Note: The statements were lifted verbatim (in their exact form) from the sources

To summarise, many thermal misconceptions are rooted in Western history and are part of Western language. Some of these misconceptions have been examined in published works for decades and continue to be prevalent to this day (see, e.g. Barnett, 2011). The prevalence of such misconceptions statements for decades reflects the lack of serious efforts to challenge such ideas, which led to the embedding of erroneous statements in people's minds.

There have been many studies in non-western countries. For example, alternative conceptions about heat, temperature, and pressure among Indian undergraduate physics students were investigated by Pathare and Pradhan (2005) using open-ended tests, a multiple-choice quiz, and interviews. The respondents failed to provide correct responses to three out of 11 questions about temperature, thermal equilibrium, and pressure. The authors explained that because students' misconceptions are easily formed, addressing such misconceptions is essential. Otherwise, these erroneous ideas will freely linger in a student's conceptual framework. The authors also stated that overcoming a student's misconceptions must begin with learning about the misconceptions and creating a direct disequilibrium in the student's mental structure to reaccommodate the set of conceptions to correct categories. Pathare and Pradhan identified teaching methods that failed to create conflict in students' minds about what they already know and what they have yet to learn as sources of misconceptions and contributors to the development of such ideas. This situation, when combined with terminologies that differ in everyday and school language, causes misconceptions that can take over beliefs. According to the authors, these two factors, along with a student's inability to overcome them independently, create an environment that supports the formation of misconceptions.

The prevalence of misconceptions regarding heat, temperature, and boiling among primary school students in Turkey was investigated by Kirikkaya and Güllü (2008) to ascertain the effectiveness of the new science curriculum, which was designed to incorporate the most common science misconceptions into primary education and help overcome students' misconceptions, four years after curriculum implementation in 2004. The test used by the authors consisted of 13 multiple-choice items and five open-ended questions and was administrated to 300 Turkish students in Kocaeli Province. Of these students, 60 were interviewed using a semi-structured design to support the questionnaire findings. After four years of implementing the new science curriculum in primary education, students in primary schools continued to exhibit a high percentage of misconceptions regarding heat and temperature, similar to that recorded before the implementation. Almost half of the sample students who studied under the new educational system stated their belief that cold materials do not have heat. Kirikkaya and Güllü suggested that these concepts are extremely difficult for Year 5 students to understand and stated that including students' misconceptions in the new curriculum may be an insufficient measure for overcoming them. According to the authors, specific activities were essential.

Saudi studies published in English regarding students' misconceptions of thermal physics that target both genders and cover a large area of the country are very limited, although these works do provide valuable insights into the issue. One such research was performed by Al-Rubayea (1996), who probed into the prevalence of heat and temperature misconceptions among 1,080 Saudi students during Year 10–12 studying in six different educational districts. The cross-age research used an instrument based on Erickson (1980) work, which adopted an instrument consisting of 16 multiple-choice questions and five tiers (answer/ reason/ confidence/ sense/ source). Four out of these 16 questions focused on heat and temperature. The author also explored the effects of differences in gender, educational level, and school location on the students' understanding of science concepts. The results revealed that the most dominant source of misconceptions was guessing and that the students' misconceptions regarding heat and temperature reached 94%. No cross-age difference in performance was found among the students; all their performance levels were low, but that of the Year 10 students was the lowest in general. According to the author, no consistent trend was detected in terms of reasoning for response selection; different students chose different reasons for why they provided a correct or incorrect answer. Most of the students who provided correct answers and most of those who chose incorrect answers stated that they were guessing. No correlation was found between students' misconceptions and their gender, grade level, and school location, but a positive correlation was found between students' confidence in their responses and the rationality of their answers. In addition to guessing, the other sources of misconceptions were physics textbooks and everyday experiences (Al-Rubayea, 1996).

To sum up, Turkish and Indian studies showed a massive prevalence of thermal misconceptions among students. The Turkish study by Kirikkaya and Güllü (2008) pointed out that even the incorporation of thermal misconceptions into a science curriculum is an inadequate measure for overcoming students' misconceptions because the nature of thermal concepts is difficult for primary school students to comprehend. The Indian study by Pathare and Pradhan (2005) identified terminology as one of the causes of students' misconceptions. On the other hand, the Saudi study by Al-Rubayea (1996), which used a unique multiple-tier test (up to five tiers), covered a huge sample of both genders and grade levels across numerous locations in Saudi Arabia. The findings showed that misconceptions occurred in up to 94% of students and that both students with correct and incorrect answers indicated that guessing drove their response selections.

In addition, the level of understanding of college, undergraduate, and post-baccalaureate students regarding the fundamental concepts of thermal equilibrium and heat transfer was investigated by Jasien and Oberem (2002). The study, which was conducted in a public institution in San Diego, Orange, and Riverside, California, and a private institution in San Diego, California, also involved 61 in-service teachers in Year K–12 with a post-baccalaureate certificate in natural science and teaching experience spanning 1 to 30 years. The participants were mostly native English speakers. Jasien and Oberem designed a two-tier (answer/confidence), multiple-choice survey to assess the participants' understanding. Their quantitative results showed confusion among the teachers and college students who majored in physics regarding thermal equilibrium concepts and the relationship between specific heat and the final temperature reached during heat transfer. The authors emphasised that thermal equilibrium is a principal concept for understanding thermal physics. Notably, the students who studied organic chemistry in the private institution and received the most comprehensive training and the most recent education on the study of heat and material temperature showed less understanding than expected, with nearly one out of two answering a question incorrectly. All the participants' answers barely exceeded the guessing level (20%) and reflected a lack of skill in interpreting graphs. The authors noted that terminology may have played a role in the students' confusion regarding the 'unfortunate term' (p. 891) of heat 'capacity'; the definition of 'capacity' in English may have caused students to think that an object can only hold a certain amount of heat. The study revealed a substantial lack of understanding of the key principles of heat and temperature, specific heat, thermal equilibrium, and heat capacity, even among the highly experienced teachers. Jasien and Oberem (2002) stated that introductory course designs may drive students to concentrate on mathematical problem solving rather than understanding principles. This claim was inferred on the basis of the unreliable information given on the test by students at the introductory level of study.

The understanding of adolescents, adults, and experts regarding heat energy and temperature concepts was investigated by Lewis and Linn (2003) using a cross-age longitudinal, two-part investigation designed to improve the Computer as Lab Partner (CLP) curriculum implemented for middle school students. The first phase of the study was intended to identify students' intuitive beliefs, with the results revealing a classic disparity between school knowledge and everyday knowledge. The second phase delved into the effectiveness of the design of the middle school curriculum on the basis of Disessa (1988) work. Lewis and Linn (2003) administered a seven-item, multiple-choice pre-test to 151 American Year 8 students and conducted many classroom and laboratory activities to foster students' understanding and reinforce the implemented curriculum. A post-test was administered following instruction and was supplemented with semi-structured interviews with 37 middle school students, nine adults, and eight chemists and physicists to obtain their predictions and explanations of everyday phenomena and ascertain which circumstances may elicit alternative explanations. Almost 80% of the students believed that aluminium foil is the best material for keeping beverages cold, which contrasted with their response that materials that keep objects warm also keep them cold (82%). The interviews showed that the respondents do not use wool to keep beverages cold because 'wool warms things up', 'wool conducts heat', and 'wool generates heat' (p. 162). From the students' points of view, conductors keep objects cold and insulators keep them hot. According to the authors, classroom/laboratory-based activities have a remarkable effect on students' understanding of thermal phenomena compared with the use of the CLP curriculum alone.

The results also revealed that the students usually rely on their intuitive conceptions when asked to explain events that are not found in their textbook or which they have not specifically learned in school. The students' intuitive conceptions were presented with strong testimonials and lengthy descriptions versus their attempts at scientific explanations. Lewis and Linn (2003) attributed the students' naïve conceptions to their efforts at making sense of the world, in which they combine their observations and their personal experiences in what is called an 'intuitive conception' (p. 162) that is reinforced by everyday language and personal experience of the natural world. The study indicated that even highly educated individuals, such as scientists, encounter difficulties in explaining everyday phenomena, albeit they provide more accurate explanations regarding predictions and theoretical definitions of terms than do students. No relationship was found between the participants' educational levels and the accuracy of their responses. The authors concluded that the students' intuitive conceptions regarding thermal phenomena are prototypes that are robust, persistent, well-established, widespread, and multigenerational. The authors additionally noted that such intuitive conceptions, which result from common sense, can aid the learning process if used in appropriate and creative ways. Finally, Lewis and Linn (2003) emphasised that the separation between school knowledge and everyday knowledge proved difficult for students who endeavoured to understand phenomena that did not correspond with their experiences.

In another study, Harrison et al. (1999) looked into the alternative conceptions of Year 11 Australian students regarding heat and temperature using a combination of concept substitution strategies and inquiry approaches grounded in Ausubel's constructivism theory (p. 55). They pointed out that heat and temperature conceptions are often 'poorly differentiated' (p. 55) and that students easily confuse heat and internal energy.

A longitudinal cross-cultural study was carried out by Meltzer (2004) to scrutinise 653 American students' reasoning regarding heat, work, and the first law of thermodynamics in an introductory calculus-based general physics course at Iowa State University. The author administered a written free-response quiz to the students and observed their reasoning over a period of three years. He also administered a multiple-choice questionnaire to 407 of the students and interviewed 32 students with different major and minor specialisations to confirm the questionnaire's findings. Any alternative conception receiving a minimum of 20%–25% of responses was regarded as a misconception. The study uncovered a total of 10 popular misconceptions on the following: temperature and molecular kinetic energy, state function, work, work as a state function, heat as a state function, cyclic process, net work done and net heat transferred equalling zero, thermal reservoir and isothermal processes, pressure-volume diagrams, and the first law of thermodynamics. The author concludes that the results showing low average class performance may be misleading, and the participant interviews indicated that each student's average performance was higher than the class's average performance. Meltzer concluded that students in the United States, on average, share the same misconceptions previously reported in Europe and the United Kingdom. The author likewise asserted that the failure to understand fundamental principles, such as heat transfer, affects the comprehension of advanced concepts. As determined from the questionnaire and interview responses, around 38% and 47% of the students, respectively, believed that ‘heat is absorbed by the system during processes’ (p. 1438)—a misconception that was attributed to the confusion caused by the use of the same units of measurement for heat, work, and energy; terminology; everyday language; approximations; generalisations; traditional instruction; a weak grasp of heat concepts; and cursory information about thermal concepts in textbooks.

The proliferation of heat and energy misconceptions among 373 undergraduate engineering students was investigated by Prince, Vigeant, and Nottis (2012) using the Heat and Energy Concept Inventory (HECI), which was developed by the researchers on the basis of Richardson (2004) iterative steps strategy. The two-tier (answer/reason) questionnaire, with 36 multiple-choice items and four dimensions of concept areas, was modified from the literature (Prince et al., 2012). The total HECI scores of the students in the pre-tests and post-tests were around 50% and 55%, respectively, indicating that one semester of instruction and activities resulted in minimal performance progress from failure to passing. The pre-test results showed that half of the students were unaware of how temperature is accurately measured and that this proportion increased to almost 54% in the post-test. More than 40% of the students confused heat and temperature, with the percentage improving slightly by the end of the semester after the post-test. The researchers declared that the students’ misconceptions originated from standard instruction that is insufficient to overcome prevalent and resistant misconceptions. The authors also mentioned that students with different major and minor specialisations experienced difficulty in understanding the nature of thermal physics, as similarly explained by Chi (2008).

To sum up, numerous thermal misconceptions found in various nations are more likely rooted in the language used in these nations. For instance, the same misconception statements regarding heat, work, and the first law of thermodynamics were found in Belgium, Germany, the United Kingdom, and the United States. Terminologies and inadequate physics courses are some of the major reasons behind students' misconceptions in the West, and lack of information regarding many of the natural phenomena learned in school or found in textbooks is most likely responsible for students' intuitive conceptions.

The next section presents a review of evaluation studies on thermal physics misconceptions using the Thermal Concepts Evaluation Instrument, with a focus on those conducted in Turkey, India, Korea, Nigeria and Saudi Arabia. This decision was prompted by the need to determine whether the thermal misconceptions reported in the Western context are also prevalent in the three aforementioned countries and how researchers explained such occurrence.

2.5 Studies Using the Thermal Concept Evaluation Instrument

The Thermal Concept Evaluation (TCE) was developed by Yeo and Zadnik (2001) to investigate students' misconceptions regarding thermal energy concepts. The test is a one-tier instrument consisting of 26 questions with multiple answer options that cover 35 popular misconception statements about thermal energy. All its distractors are misconceptions, which are categorised under four statements on thermal energy areas that are also listed as students' alternative conceptions. The category of heat is allocated nine questions; temperature, 15 questions; heat transfer and temperature change, 16 questions; and thermal properties of materials, 17 questions. Notably, an overlap in questions is evident for different misconceptions. The authors administered the test to 478 students in years 10–13 (equivalent to Year 10 - first Year University) in Western Australian government schools. A split-half test was used to examine the reliability of the test, and the Spearman–Brown test was carried out to determine item correlation (Yeo & Zadnik, 2001).

The TCE has been used by Luera, Otto, and Zitzewitz (2005) to investigate the effectiveness of using a misconception-guided instructional approach in delivering basic concepts regarding thermal energy to 47 pre-service elementary teachers studying at the University of Michigan-Dearborn. The approach is based on conceptual change theory (i.e. Luera et al., 2005) and consists of five steps: identify, assess, analyse, design, and reassess. The results showed an increase from 20% to almost 80% in the students' understanding of thermal concepts, as evidenced by their responses to 13 of the questions in the TCE post-test, which was administered after instruction (Luera et al., 2005). The performance of the respondents in answering two questions remained almost the same after instruction, and their performance in responding to two questions reflected a decline in understanding after instruction. These results indicated that the percentage of students who had misconceptions regarding these question items increased. According to the researchers, misconceptions regarding the most likely room temperature increased by almost 10% after instruction. An increase in percentage was also observed with respect to misconceptions regarding the final temperature of a mixture of different quantities of water at different temperatures. The same group of researchers conducted the same study to investigate the misconceptions of pre-service elementary teachers studying at the University of Michigan-Dearborn in 2006. Over 90% of students majoring in science held misconceptions about why a pressure cooker is used to cook food; this percentage dropped by 20% in the post-test, which was administered after instruction. Almost 90% of the students harboured misconceptions about boiling water at high altitudes; this percentage decreased to 50% in the post-test. In general, there was improvement in student performance in the post-test with respect to almost all but two of the questions (Questions 7 and 17), which reflected an increased occurrence of misconceptions after instruction. Question 7 revolves around the final temperature of mixed cups of water at different temperatures, and Question 17 is about the most likely room temperature. For 23 questions, the students answered over 50% of the time with misconceptions in the pre-test. This proportion decreased to 11 questions in the post-test. The researchers suggested that the students' answers were more likely driven by lack of knowledge than misconceptions.

Başer (2006) used a translated version of the TCE to investigate the understanding of 82 Turkish pre-service teachers (27 males, 55 females) regarding thermal energy concepts. Both control and experimental groups were tested using the original 26-item test, to which the author added two extra questions regarding thermal insulation. The test was then piloted to 430 second-year pre-service teachers, and both respondent groups received different types of instruction (cognitive conflict vs. traditional instruction. The results showed a significant improvement in the experimental group's scores after instruction. The pre-test mean values were 9 and 8, and the post-test mean values were 17 and 11 for the experimental and control groups, respectively. In the pre-test, over 80% of the controls exhibited misconceptions about the meaning of water bubbles and what components are found inside them. More than 80% of the control group also believed that heat is a substance, and the same percentage was of the opinion that there is no limit to the lowest temperature. In both the control and experimental groups, over 80% regarded heat flowing more slowly through conductors as true, thereby making objects feel hotter. Başer expressed confusion over the students' inability to give a response to why a pressure cooker is used to cook food and recommended cognitive conflict-based instruction as an approach to rectifying students' misconceptions.

Georgiou and Sharma (2010, 2012) also examined the effectiveness of the TCE in detecting the thermal energy misconceptions of 938 Australian first-year university students (attending fundamental, regular, and advanced courses) and second-year university students (majoring in physics). The authors probed into four of the students' misconceptions using the first six questions in the TCE. Among the students attending fundamental courses, 79% held misconceptions regarding steam temperature, and 40% believed that water always boils at the same temperature. Of the second-year students, almost 40% harboured misconceptions about the thermal properties of materials, and 18% regarded the statement that water cannot have a temperature of 0°C as true. Almost 60% of the students learn either fundamental or regular courses and over 20% of the second-year students learn advanced courses believed that objects in thermal contact can have different temperatures.

The results of Georgiou and Sharma (2010, 2012) studies found a cross-age decline in the students' alternative conceptions. They also discovered that experts and novices exhibited different types of misconceptions and that the students responded to the same alternative conceptions differently when they were used in different situations. Most of the respondents unsuccessfully answered the questions related to the aforementioned conceptions. Georgiou and Sharma declared that the students' misconceptions originated from the historical confusion caused by terminologies related to heat and pointed out that many researchers have called for either a clarification of the term or its replacement with the word 'entropy'. The authors additionally recommended the development of a tool for differentiating between misconceptions and ignorance.

Alwan (2011) used a translated version of the TCE to investigate the misconceptions of 53 Libyan students regarding heat and temperature. The sample comprised university students majoring in physics, chemistry, biology, and mathematics at Al Fateh University in Libya. The test consisted of 30 items: the 26 original questions, two questions taken from Driver (1985) and two questions taken from Elwan (2007) work (as cited in Alwan, 2011). The author found that the highest percentages of misconceptions were those related to the statements 'bubbles mean boiling' and 'the bubbles in boiling water contain air, oxygen or nothing' (Alwan, 2011, p. 604). None of the students answered the related question correctly. Misconception occurrence ranged from 40% to 100%. Alwan stated that the misconceptions were due to everyday experiences that are falsely interpreted by the students. The author concluded the study by indicating that the Libyan students experienced difficulty in understanding heat and temperature in a pattern similar to the experience of students across all other cultures.

A translated copy of TCE into the Korean language was used by Chu, Treagust, Yeo, and Zadnik (2012) to investigate the understanding of 515 Year 10–12 Korean students regarding thermal energy. The authors used 19 out of the 26 items in the TCE instrument and found no indication of cross-age development in the understanding of the students. The test was piloted to 30–35 students to check face value reliability, and the influence of three independent factors—school year, educational level, and thermal energy topics currently and previously studied—on student performance was examined. Thus, several items in the original version of the test were excluded due to minimal responses. The authors regarded any alternative that received 20% or more of the responses as a misconception. The authors stated that differentiating between heat and temperature is the key to understanding thermal physics. They attributed the students' misconceptions to the differences between the language used in school and the language used in daily life (e.g. the terms for coldness and hotness). The results showed little to no significant correlation between students' understanding of thermal physics and the grade the students were in. A positive correlation was found between students' understanding of thermal physics and the current science subjects studied, wherein the students currently studying chemistry and physics showed better general understanding than the others. The findings indicated that the heat conductivity and equilibrium questions had the highest misconception percentage (lowest number of correct answers). Open-ended questions were recommended by the authors as a means of deriving a better idea of why students face difficulties in understanding thermal physics concepts.

Kácovský (2015) examined Czech Republic secondary school students' understanding of thermal physics using a translated copy of the TCE. The researcher noted that thermal physics is not a popular topic among Czech students, which can explain their difficulties in understanding thermal concepts. A modified TCE with 19 questions was used for a pilot study involving three secondary school students to determine the intelligibility and adequacy of the instrument. The author shared his plans to develop several experiments for improving students' comprehension of thermal concepts.

A shortened copy of the TCE was translated into Bosnian by Hadžibegović and Sulejmanović (2014) to explore 94 first-year chemistry students' misconceptions of thermal energy. Up to 95% of the students held misconceptions regarding thermal energy change and heat flow. This result was attributed to the fact that the students had no factual knowledge regarding heat, temperature, and internal energy. Of the students, 13% believed that the same amount of heat is held by different materials, and 22% believed that temperature can be transferred. Two of the questions received no more than 5% and 10% correct answers. Out of a score of 1,880 points, the participants earned only 49% of those ascribed to explanations for one of the options in Question 6. The researchers blamed the students' misconceptions on class size (around 100 students per class), which limits the working space of the students; the imposition of time limits; the use of an instructor-centred learning approach; and resistance by the students to learn more.

Louzada, da Fonseca Elia, and Sampaio (2015) used the Brazilian version of the TCE to examine the thermal energy misconceptions of 151 second-year high school students in Rio de Janeiro, which is equivalent to Year 10 in the Australian educational ladder. The test was readministered to the students after one year of studying the related materials. The pre-test results showed that almost 70% of the students held alternative conceptions regarding thermal energy, but the post-test findings reflected a decrease in such conceptions to almost 52% after instruction. The students exhibited, on average, the same level of understanding of thermal energy as that displayed by Australian high school students. The Brazilian students' alternative conceptions regarding four categories of the test decreased by up to 9%. The lowest decline in alternative conceptions was that for the temperature category, indicating that some alternative conceptions about temperature are more robust than others. For instance, the proportion of students who believed that 'heat is a substance' declined by 29%, but the percentage of students who believed that 'heat and cold are different' (p. 6) remained almost the same. Additionally, the percentage of students who were of the opinion that something is wrong when boiling temperature remains constant declined by 19%, whereas the proportion of students who were convinced that 'there is no limit on the lowest temperature' (p. 7) remained almost the same after one year. The percentage of students who believed that 'heating always results in an increase in temperature' declined by 23%, but percentages remained the same for those who believed that 'heat and cold flow like liquids', 'objects of different temperatures that are in contact with each other at different temperatures do not necessarily move towards the same temperature', and 'kinetic theory does not really explain heat transfer' (p. 7). The proportion of students who were of the opinion that 'ice is at 0°C and/or cannot change temperature' declined by 42%, but those who were convinced that 'materials such as wool have the ability to heat things up' (p. 8) remained almost the same. Further analysis was recommended by the authors.

A Nigerian modified version of the TCE has been used by Madu and Orji (2015) to identify changes in the conceptual understanding of 249 Nigerian secondary school students. The authors made alterations to the TCE by increasing the number of tiers from one to two tiers as well as restricting the number of options in each question to four options per item. The students were divided into a control group, which was taught with the traditional approach, and an experimental group, which was taught using cognitive conflict-based physics instruction. Pre-tests and post-tests were administered to both groups before and after instruction. The students' responses were evaluated on the basis of the Westbrook and Rogers (1992) scale of 0 to 3 to denote understanding (As cited in Madu & Orji, 2015). Code 3 represents full scientific and sound understanding, which is the level most highly preferred as denoting an acceptable level of performance; Code 2 represents transitional conception, which reflects students' abandonment of their naïve conceptions; Code 1 signifies the harbouring of alternative or naïve conceptions (AC); and Code 0 represents no conception (NC). The findings indicated that both the experimental and control groups at all levels of understanding were at the same preconception state. After instruction, the experimental group's AC state increased by 1.5%, and that of the control group remained the same. Even with traditional teaching, some of the students in the control group managed to progress to having sound understanding (Code 3). The majority of the students (70%) in the experimental group remained at or shifted to either sound understanding or a more refined understanding after instruction based on cognitive conflict. The study also showed that the misconceptions of students at the AC/NC level were more resistant to change, indicating the robustness of the misconceptions.

In another Arabian study, Nawafleh et al. (2016) used the TCE to explore the heat- and temperature-related misconceptions of 188 second- to fourth-year students at Yarmouk University in Jordan. Independent factors, such as gender, academic level, academic score, and studied thermodynamics courses, were investigated in relation to the students' misconceptions. Among the students, almost 60% held misconceptions related to thermal energy, with the highest misconception percentage being almost 79%. No correlation was found between gender or academic level and the students' levels of misconceptions. However, a positive correlation was found between the students' levels of misconceptions and their academic scores and whether they had taken a thermodynamics course or not. The authors recommended analysing students' misconceptions sources and stated that teaching thermodynamics introductory courses to undergraduate students majoring in physics is essential. The undergraduate students' misconceptions were attributed to the lack of information from previous education, secondary physics textbooks, teachers' training programs, teaching methods, and abstract concepts. Nawafleh et al. identified abstract physical concepts, textbooks, pre-service teachers' preparation programs, and teaching methods as the specific drivers of high misconception occurrence.

The preceding discussion revealed a wide range of methods used to uncover students' misconceptions. The results of the reviewed studies indicated extensive misconception prevalence among students in different levels of education and disciplines. These misconceptions have been confirmed as embedded in participants' language. Almost all the reviewed studies suggested the use of different teaching and learning techniques as the ultimate solution to converting erroneous prior knowledge into 'correct' knowledge. The high percentage of misconception occurrence around the world has prompted researchers to wonder whether all students' wrong answers originate from misconceptions or lack of knowledge. This issue highlights the need for a tool that can differentiate between lack of knowledge and misconception.

2.6 Possible Sources of Students' Misconceptions

The knowledge revolution in Europe started around the mid-18th century, during which the industrial revolution began to emerge. As time passed, 'old-fashioned' scientific theories were replaced with 'modern' ones, although some of the former remained in people's minds. Individuals were unable to keep pace with the rapid updates prompted by modern theories (Vosniadou, 2013). Not everybody in the Western world, for instance, made the transition from non-valid theories to updated ones, as evidenced by the continuing proliferation of the statement 'heat is a substance'. Callendar (1912) argued that scientific misconceptions in Western nations are caused by transition from the traditional caloric theory to the modern theory of kinetics. The author stated that old theories contain many obscure and vague statements. Harris (1981) pointed out that concepts such as heat, heat flow, and heat capacity, which are related to caloric theory, have been prevalent in the education of elementary school students across France (Tiberghien, 1980), Canada (Erickson, 1975, 1979, 1980), the United States (Albert, 1978), and England (Shayer & Wylam, 1981). Shayer and Wylam (as cited in Hewson & Hamlyn, 1984) found that the caloric model is used by around 80% of students aged 10 and 13. In addition, Fuchs (1987) believed that thermal energy misconceptions date back to 1850 (In Novak, 1987).

In modern times, the delineation of misconception sources continues. Although the sources of students' misconceptions about science are mostly unidentifiable (Helm, 1980), some researchers attributed faulty reasoning to students themselves (Abu-Tair, 2009), whereas others pointed to teachers as sources of misconceptions (Barrass, 2010). Erroneous perceptions can also originate from textbooks (Barrass, 2010; Deshmukh & Deshmukh, 2011; Kavşut, 2010), teaching methods (Alharbi, 2012), and learning strategies (i.e. Thijs & van den Berg, 1995). Abraham, Williamson, and Westbrook (1994) and Gönen and Kocakaya (2010) identified student age and brain development as misconception sources, whereas Nawafleh et al. (2016) highlighted the quality of learning environment as playing a role in students' misconceptions. Misconceptions can likewise be spread by books and articles, as asserted by Ralya and Ralya (1938), and everyday language, as discussed by Lewis and Linn (2003). This problem is particularly evident in developing countries (Padalkar, 2010).

Identifying the sources of students' misconceptions is not easy as some of these misconceptions are well embedded in the students' minds in many nations. Despite differences among studies with respect to identified sources of students' misconceptions, however, parallel views regarding the best explanations for everyday phenomena may exist because each culture has access to the knowledge sources found in other cultures. This section reviews studies on the most common misconception sources that have been identified.

2.6.1 *Language and Terminology*

The roles of language and terminology in the formation of students' misconceptions have rarely been explored in the literature, especially with regard to the Arabic language, but certain streams of research have been able to provide illuminating findings. Yahiel (2009), for example, published a study in the Arabic language to explore the impact of language and terminology ambiguity on primary school students' learning of science concepts in Israel. The author discussed the use of the terms 'weight' and 'mass' in middle school science curriculums (issued in 1996). He noted that 'mass' had been used for the previous 20 years in all Arabic academic and educational documents but had not existed in science textbooks as recently as the 1970s and the 1980s. Instead, the term 'weight' was used frequently. As a result, many Year 7 science textbooks once stated that an object's weight can be measured by a scale in kilograms. The author reported that the term 'weight' in the previous statement was replaced with 'mass' in later Year 7 science textbook editions. He also indicated, however, that although some recent textbooks define mass as the amount of matter measured by a scale in kilograms, others still use the term 'weight'. The author claimed that such changes in the terms and concepts used in textbooks are driven by international examinations versus a true need. The author cited Dr. Tzachi Milgrom (A member of the physics and chemistry divisions at the Ministry of Education's Curriculum Center at Hebrew University of Jerusalem (1993) introduction to a Teachers' Science Handbook as follows:

> 'It is not ideal using wrong terms and later we seek ways to get rid of them; thus, from now on, the term 'mass' must take place, even if there is no logic behind using this term or why the term 'weight' cannot be used; however, the term 'mass' can be used without extra explanation, especially because the terminological revolution is not sharp in students' minds, and

> all what we are talking about is just changing the term name, while measuring devices and units are still the same' (Yahiel, 2009, p. 1).

Yahiel (2009) stated that some misconceptions are resistant because certain concepts have meaning in both scientific and everyday language. For instance, the terms 'solid' and 'hard' have the same meaning in Arabian everyday language, but 'solid' in scientific language means a state of matter. Thus, students do not consider powder as a solid. The author explained that these examples are not rare cases; many concepts have dual meanings in the Arabic language, such as matter, force, body, volume, work, energy, heat, temperature, waves, cell, tissue, and living organisms, to name a few. In school, teachers expect students to use concepts in their scientific forms, yet students continue using their everyday variants.

Returning to the term 'mass', which is rarely used in everyday language and is thus unfamiliar to most students, confusion about using mass and weight led to the deletion of the term 'weight' from all Arabic primary science education textbooks in Israel, although scales are still mentioned. Contradicting Milgrom's (1993) call to eliminate the use of incorrect terms in science textbooks, Yahiel (2009) claimed that there is nothing wrong with using incorrect terms as long as students are accustomed to these science terms. He reasoned that up to the secondary educational level, students' science learning generally consists of 'the particle model of matter', which does not necessarily require learning about mass, and that students in early educational levels are insufficiently mature to grasp changes to terms. Instead, the author recommended using the incorrect term in the primary educational level and earlier—if it can help develop students' cognitive learning—and negotiating the use of the two terms (weight and mass) from Year 7 and beyond, during which students would then be mature enough to understand why such a change is necessary. The author also warned against making huge alterations to students' collection of concepts, stating that such changes may damage the cognitive development process (Yahiel, 2009).

The importance of language to understand science concepts also has been explored by Brookes and Etkina (2015) who found that some thermal terminology, such as the term 'heat', is hard to define using the scientific definition and at the same time keep it grammatically correct. This idea of using the term 'heat' once as a noun, once as a verb, once as an adjective, and once as an adverb is discussed by Erickson and Tiberghien (1985); and by Romer (2001) who suggested that the grammatical identity confusion of 'heat' might lead to much confusion about the nature of the heat. Yet, many researchers and educators agree that the use of the term 'heat' as a verb is grammatically correct in context (Brookes & Etkina, 2015).

2.6.2 *Textbooks as Possible Sources of Students' Misconceptions*

Textbooks are a historical source of students' misconceptions (Erman, 2017; McComas, 2018; Zajkov, Gegovska-Zajkova, & Mitrevski, 2017). Almost all studies on students' misconceptions blamed textbooks for its role in the formation of erroneous ideas because of missing information, ambiguous language, and misleading Figures and examples in such materials.

The prevalence of physics misconceptions in an elementary school science textbook series was investigated by Weaver (1965), who pointed out that physics misconceptions are widely spread among in-service and pre-service elementary school teachers—an occurrence that the author ascribed to textbooks. He inspected 12 science textbook series for their potential to contain misconceptions, ambiguous language, errors, and/or confusing presentations. None of the materials reviewed were free of physics misconceptions. Weaver further explained how elementary school science teachers, who are usually teachers' out-of-field, depend heavily on science textbooks. Eight of the inspected textbooks promoted the false idea that a simple machine can produce more work than that incorporated into it. Ambiguous statements about this idea were found in two other textbooks. The terms 'force' and 'pressure' were occasionally confused in the materials, and 'weight' and 'mass' were commonly confused in the examined series. Weaver likewise found extremely confusing statements about the nature of heat (e.g. 'Electricity, light, and heat are forms of energy. They are forces, not matter'. [1965, p. 234]). Other such statements present the following ideas:

- A transformer reduces a strong current into a weaker one.
- Static electricity is useless.
- Electricity is produced by friction.
- Magnetism and electricity are forces.
- Electric current always takes the shortest route.
- Volt is a unit of electrical pressure is the potential difference [The term electrical pressure was used in this reference as voltage].
- Gravitational force depends on the size (volume) of bodies.
- The moon has centrifugal force.
- Isotopes are different types of the same atom.
- Cool air weighs more than warm air.
- Pressure refers to the push of air.

Weaver suggested that authors of school textbooks should present more accurate information and consult experts in each field about which they write. The science textbooks reviewed by Weaver (1965) have numerous phrases, Figures, pictures, and examples that promote the formation of misconceptions among students and their teachers. Similar studies with such valuable and comprehensive information are not easy to find. In addition, Hazen (1899) pointed out that the American biological textbooks that he reviewed was filled with errors and misconceptions, making the textbooks 'as to be of little value' (p. 211).

It seems the issue regarding textbook unreliable content continues even in recent years. In Turkey, for instance, Aycan, Kaynar, Türkoğuz, and Ari (2002) investigated science textbooks for Year 6–8 students. The textbooks were published by three different publishers and were used as primary school science resource materials. The authors examined each textbook in accordance with the following criteria: physical properties, educational features, visual design features, and narrative and language features. The A series textbooks (Year 6–8) contained 688 errors: 253 in the Year 8 textbook, 231 in the Year 6 textbook, and 204 in the Year 7 textbook. The Year 6 textbook had the highest number of incorrect/missing information errors, and the Year 8 textbook had the highest number of errors in pictures, charts, Figures, and Tables, as well as the highest number of experimental instruction errors. The C series textbooks (Year 6–8) had 521 errors, with most being incorrect/missing information errors and errors in pictures, charts, Figures, and Tables found in the Year 6 textbook. Finally, the B series textbooks (Year 6–8) had 437 errors, with most being incorrect/missing information errors and errors in pictures, charts, Figures, and Tables in the Year 6 and 7 textbooks. The authors, who identified five pages of erroneous and deficient statements in the publishers' textbooks, stated that they hoped their critical investigation can help progress elementary education by identifying the right materials for use at each grade level.

Another study focusing on Turkish textbooks by Kavşut (2010) investigated the Year 6 science and technology textbook series *Pasifik* (2008–2009) for its potential to present misconceptions and ambiguous language. The author concentrated on the section titled ‘Reproduction, Growth and Development in Living Organisms’. The examination uncovered a considerable proportion of unclear shapes, invalid models, ambiguous content, and erroneous and deficient statements. Some of the misleading and inaccurate statements included ‘the number of human body cells is fixed, regardless of age’ and ‘the movement of sperm depends on its size and shape’. The author also found incorrect terms in the textbook, with the material mixing up ‘childhood’ with ‘babyhood’. Considerable information was missing from image captions, and many pictures were modified in terms of colour, size, and detail, with no justification, which could lead students to mistakenly believe that intestines are (for example) green, and lungs are red. Pictures related to certain activities and questions were unhelpful in making correct predictions and providing correct answers.

In India, Padalkar (2010) found that the concepts of ‘horizon’ and ‘local directions’ were missing not only from Indian textbooks but also from well-known books published in India. Another study about the potential of Indian textbooks as sources of students’ misconceptions was carried out by Deshmukh and Deshmukh (2011) who reviewed both state board syllabus biology textbooks (Year 9) and central board syllabus biology textbooks (Year 10) for their potential to contain misconceptions. The authors stated that teachers in India rely heavily on textbooks as a source of information because these are the only materials available in most Indian schools. Focusing on the ‘Life Processes’ section of the books, they found that critical facts and information about the function of each part of the heart and the circulatory system were missing. Diagrams of the heart were unclear with regard to oxygenated and deoxygenated blood flow as well as the colour of blood. Although the heart functions as a pump, it was associated in the books with terms such as ‘blood purification’, ‘filtration’, ‘formation’, ‘pure/impure blood’, ‘oxygen rich’, and ‘carbon dioxide rich’. The textbooks also listed respiration modes as ‘cutaneous respiration’, ‘bronchial respiration’, ‘tracheal respiration’, and ‘pulmonary respiration’ but do not mention plant respiration. Information on cellular respiration was confusing, and the suggested activities were vague. Finally, information about when photosynthesis and respiration occur in plants did not appear in any of the textbooks.

Many Arabian studies have reviewed textbooks, but nearly all focused on the availability of common concepts in textbooks and not the most common misconceptions. For instance, Al-ghaleeth (2008), Rasras (2011), and Salem (2011) found many alternative conceptions embedded in Palestinian science and mathematics textbooks, combined with unclear images and Figures that may cause misconceptions.

In Jordan, Al-Malkawi, Al-Ani, and Abass (2008) probed into the solar system conceptions in a Year 9 earth sciences textbook and evaluated the materials as insufficient in its level of information and having the potential to induce the development of misconceptions in students’ minds. In the Bahraini context, Buqahouse (2009) called attention to the lack of an orientation towards critical thinking skills in middle school science textbooks, stating that such deficiency may result in students’ misconceptions of science. In the Saudi context, Assoleem (2002) found unclear concepts linked to chemical and biochemical changes in a Year 7 science textbook, which the author suggested as leading to the formation of alternative conceptions.

A limited number of studies have investigated the science textbooks used in Arabian countries mostly because the textbooks are translated from Western versions. This is probably the reason why other researchers disregard these materials as potential avenues for the promotion of student misconceptions of science.

2.6.3 *Teachers' Practical Knowledge as a Source of Students' Misconceptions*

The role that teachers' practical knowledge plays in teaching and learning operations has been discussed by van Driel et al. (2001). From their perspective, any reform to the education system that does not consider teachers' existing knowledge, beliefs, and attitudes is more likely to fail. The authors described teachers' practical knowledge as a combination of experimental knowledge, formal knowledge, and personal beliefs. Haney, Czerniak, & Lumpe, 1996 stated that concentrating only on developing certain teachers' skills is not enough to establish successful science education reform (as cited in van Driel et al., 2001). According to van Driel et al., the most important step of any science education reform is making radical changes in teachers' knowledge and beliefs about teaching, learning, and subject matter. In other words, the vital matter of carrying out any science education reform is teacher learning (Ball & Cohen, 1999). However, van Driel et al. (2001) emphasised that teachers' cognitions (i.e. beliefs, and official and personal knowledge) are typically stable. Thompson and Zeuli (1999) pointed out that teachers learn new materials, innovative ideas, and techniques by incorporating them into their existing practices in a tinkering manner. Thus, changing teachers' practices is not easy and cannot be done rapidly for many reasons. First, from the teachers' point of view, the practice that has constructed their practical knowledge over their career is beneficial and has proven workable. Thus, they are satisfied and see no need to take a risk by changing their practice with new innovative ideas that they are not familiar with and that may not work for them in particular. Second, at a certain time, teachers' knowledge reaches a concentration level where new information expands the teachers' experience and adds to their practical knowledge while decreasing its variety at the same time (van Driel et al., 2001). As a consequence, some consider teachers' practical knowledge to be conservative (Tom & Valli (1990) as cited in van Driel et al., 2001).

In their study, Yerrick, Parke, and Nugent (1997) found that teachers tend to improve their speaking regarding students and content in a variety of ways, but their fundamental views of science and teaching remain almost the same. Both Clary et al. (2018) and van Driel et al. (2001) found that a short, intensive content knowledge training program had a successful outcome regarding teachers retaining the information received during the training program. However, Clary et al. (2018) found that after 1–2 years, teachers' content knowledge regarding physics and chemistry that they received during their training course was almost the same as before the training. On the other hand, van Driel et al. (2001) found that even though teachers retained the information they received during the training program, it was hard for teachers to apply it to their practice when they were asked to do so, meaning that adding new information to teachers' existing knowledge frameworks is not as simple as once thought. van Driel et al. (2001) suggested that based on their teaching experiences, teachers need to restructure their knowledge and beliefs to incorporate the new evidence in their practical knowledge. Such teachers' resistance to changing their existing framework to reflect their practical knowledge may contribute to the development of students' misconceptions (Loughran, Gunstone, Berry, Milroy, & Mulhall, 2000).

2.7 Summary

This chapter has presented a review of studies on students' misconceptions from the early 20th century up to the present time. The review traced the development of the term 'misconception' and how students' prior knowledge has shifted from being based on superstitions and misconceptions to being grounded in alternative beliefs. Previous studies have shown that students of different ages and from varying backgrounds have enormously alternative ideas related to science and thermal physics concepts. TCE is the instrument used by many studies to evaluate students' level of understanding of thermal concepts. The results of those studies point out that conceptual change of students' old schemas regarding heat and temperature may be challenging for both teachers and students due to various factors, such as language, terminology, and textbooks. Thus, this study will investigate Saudi students' and teachers' conceptual understanding of thermal concepts using the TCE instrument and the effect of these factors in the Saudi context.

With respect to alternative conception sources, nearly all the reviewed studies indicated that the sources of misconceptions are ambiguous science language, terminology, and teachers' practical knowledge. A limited number of studies were devoted to the potential of science textbooks. However, no review was performed for McGraw-Hill science textbooks in either Arabic or English. It is hoped that the review in Chapter 7 of this thesis will fill this gap.

CHAPTER 3
STUDY CONTEXT

3.1 Introduction

This chapter comprehensively describes the specifications and context of the study. As a background to the chosen context, the history of the Saudi educational system and its development are discussed, with particular focus on female Saudi education.

The specific topics covered in the chapter are as follows: Section 3.2 centres on education in Saudi Arabia and its history, the regulatory bodies in charge of education provision, and the curriculum. Section 3.3 gives brief information about female education in Saudi Arabia. The development of education in Saudi Arabia, including education authorities and curriculum administration, and the philosophy that underlies Saudi education come under Section 3.4 and its subheading.

3.2 Education in Saudi Arabia

After more than 90 years of the official implementation of Western-based education in Saudi Arabia, an issue that has arisen is where the country's educational system currently stands. Ascertaining the condition of the Saudi educational system is difficult given the confusing nature of official permits related to the quality of education, the reality of Saudi education and the shortage of information in organisational and government websites (Aleissa, 2009). Compounding this issue are inconsistent assessments by researchers, experts and government officials.

Over time, the Saudi public was under the impression that the country's education-related challenges have been resolved, but the declaration of Dr. Aleissa[3] indicated otherwise: 'Our education system failed miserably' (2009, p. 32). The Year 2015 saw renewed hope that Saudi Arabia is moving forward with its latest educational development projects. However, once again, expectations were diminished as Dr. Amal AL-Shaman, Shura Council[4] member, claimed that Saudi Arabia's Ministry of Education (MOE) keeps concealing the truth from the public (Omari, 2015). AL-Shaman asserted that although MOE reports suggested the existence of an extraordinary educational system that is more comprehensive than those of other developed countries, data from the Qiyas National Centre for Assessment in Higher Education revealed that student achievement is currently inferior (Omari, 2015). When the Shura Council inquired into the low educational outcomes, the new Minister (i.e. Dr. Aleissa) of Education invoked his right not to answer the question (Surayhi, 2016). On another occasion, the MOE exhibited the same refusal to clarify the issue, stating the following: 'It is just your opinion, and if you can, prove it' (Surayhi, 2016).

Before the merging of the MOE and the Ministry of Higher Education (MOHe) under one department in 2015, the latter constantly criticised the achievements of the former. As the two ministries were merged, the MOHe stopped complaining about the MOE because the former was now responsible for the outcomes of both government departments. In an article published in *Okaz Newspaper*, Surayhi (2016) was critical of the merging, pointing to the bickering between the departments; the author recounted how the MOHe used to complain about high school students' a below-par

[3] Dr. Ahmad Aleissa became a Mister of Education in 2014.
[4] The Shura Council was established 1992 and is considered the highest council in Saudi Arabia. All ministries present their work to this council for evaluation and approval of funding for new projects (Shura.gov.sa).

chievements, for which the MOE was responsible, and how the MOE in retaliation used to lament the incompetent teachers who come from the higher education sector. The author added that as the education ministries have now become one ministry, universities will no longer be able to complain about schools' outcomes (students' achievements), and schools will no longer be able to complain about university education outcomes, namely, teachers' performance. Surayhi (2016) flags the issue by saying 'now no-one is able to check on the education system outcomes' (p. 1).

Apart from these contrasting views regarding education in Saudi Arabia, disagreement is also prevalent among educators who deliberate over the problems of the educational system and their causes. Errasheed, for instance, located the issues confronting the Saudi educational system in two aspects: the quality of teachers and the quality of school buildings (as cited in Khoja, 1998). Dahlan, Secretary of the Jeddah Chamber of Commerce, identified teachers, the school environment and textbook content as the sources of problems in the Saudi educational system (as cited in Khoja, 1998). Aleissa (2009) believed that the roots of the problems are the absence of a political vision about education, bureaucracy and religious culture.

With consideration for the above-mentioned issues, this study has illuminated factors that cause superficiality in student understanding. Before discussing the challenges that confront contemporary Saudi education, this chapter summarises the history of the country's educational system to determine strategies that may help prevent the recurrence of problems in the future. Although the research focused primarily on the development of female education, the educational development of both males and females is also discussed.

3.3 History of Female Education in Saudi Arabia

Saudi education formally began in 1925. The Knowledge Directorate (re-named the Ministry of Knowledges in 1954) was responsible for providing education to Saudi male citizens and prohibited women from receiving government-funded education. Thirty-five years after the initial provision of education in Saudi Arabia, females were afforded the opportunity to undergo schooling in 1960. This initiative was opposed by numerous radical religious individuals, with the groups insisting that women's roles revolve around serving their families and raising children (Aleissa, 2009). These groups eventually relented under one condition—that they be granted the authority to completely oversee women's education—a demand that was legitimised through the establishment of the General Presidency for Girls' Education (GPGE) (Aleissa, 2009). The GPGE operated under a women's protection philosophy, which the organisation implemented by isolating school and university females from the outside world. Educational institutions for girls were built with high walls, males were hired to provide policing and security and strict rules regarding dress codes in schools and universities were imposed. Women were protected at the expense of an appropriate educational environment and opportunities to expand their capabilities (Aleissa, 2009).

Having a separate educational system for girls and boys deprived the former of the chance to benefit from the educational experiences of boys, who had been enjoying the advantages of schooling for 35 years. When the GPGE began its operations, it faced a shortage of female teachers with sufficient experience but could not tap the male population to fill this gap as male teachers were not allowed to teach females. This dilemma drove the organisation to hire any female of any age who could read and write as a teacher in GPGE-administered schools and universities. Some students were allowed to advance to a higher Year level as long as they could read and write, and others were permitted to graduate from primary school (spanning six years) after completing only two years of primary education; these primary school graduates then became teachers to their peers. This situation meant that some students graduated from primary school at the age of 9 merely because of the ability to read and write, which was the minimum requirement for advancement in Year level (Al-Otaibi, 2013). In only a few years, the GPGE suffered from a massive shortage in teachers because of increased female enrolment in primary schools. This development prompted the establishment of teachers' colleges in almost every province of Saudi Arabia. For this purpose, primary school graduates were encouraged to attend the colleges, where they could obtain a Diploma in Teaching after three years of study and eventually pursue a teaching career. The GPGE then hired these graduates with little to no regard for their ability or willingness to teach (Aledadi, 2012; Aleissa, 2009).

In 1998, the teachers' colleges were converted into what were called Pre-Service Teachers' Faculty Divisions. Only high school students were admitted and conferred bachelor's degrees (practical programs) after completing two years of study. Graduates of the two-year program obtained a Diploma in Teaching and were typically employed in primary schools. That year, 22,000 female students underwent training in these institutions (as cited in Khoja, 1998). To accommodate the number of yearly high school graduates, the GPGE established many theoretically based faculty divisions, each specialising in several fields, in large cities. Teachers who graduated from the theoretical institutions after four years of study were conferred bachelor's degrees and employed in middle and high schools. The GPGE preferred employing graduates of theoretical faculties with bachelor's degrees over graduates of pre-service teaching programs with diploma degrees, thereby leaving many of the latter without jobs.

During this period, the MOHe was responsible for administering those universities that offered practical programs. The first Faculty of Education in these universities was established in 1966 after the signing of an agreement between the Ministry of Knowledges and the United Nations Organization for Education, Science and Culture (UNESCO); admission into the faculty was limited to male students (KSU.edu.sa, 2016). Teachers who graduated from higher education universities were also awarded bachelor's degrees, but these individuals were referred to as 'educational graduates', whereas teachers who completed schooling in the GPGE schools were called 'non-educational graduates'.

By 1980, the proportion of female students enrolled in colleges and universities was over one-third of the entire population of Saudi students who continued on to higher education (Roy, 1992). The Year 2002 witnessed a tragic accident in one of the Saudi female schools, where 15 little girls were burned alive, and a horrifying fire that left 50 seriously injured in one of Saudi Arabia's primary schools. The GPGE was blamed for the disaster, with the public stating that the organisation built unsafe school structures without emergency exits and located in a very narrow road that prevented fire fighters from reaching the schools. Only 12 days after the incident and after 42 years of operating educational institutions for girls, the GPGE was abolished and merged with the Ministry of Knowledges by order of the King (Samman, 2002). A year later, the Ministry of Knowledges was renamed the Ministry of Education (MOE.Gov.SA, 2016).

3.4 Development of Education in Saudi Arabia

Highlighting every attempt to improve or develop the Saudi educational system[5] is difficult. This study therefore focused on the MOE's efforts to enhance one component of the country's educational system—textbooks. Concentrating on this issue can shed light on the factors that cause superficiality in understanding among Saudi students.

3.4.1 *Saudi Educational Authorities*

In the United States, at least eight authorised national and specialised centres and associations collaborate to develop and design the country's science standards (National Research Council, 2016). These organisations are the American Association for the Advancement of Science, the American Chemical Society, the Biological Sciences Curriculum Study, the Educational Development Centre, the Lawrence Hall of Science, the National Science Resources Centre, the National Science Teachers Association and the Technical Education Resources Centre. By contrast, Saudi Arabia's educational authorities constitute three departments supported by the Supreme Committee for Education Policy. These departments are the MOE, the MOHe and the General Institutions for Technical and Vocational Training (Aleissa, 2009).

3.4.2 *Curriculum General Administration*

The Curriculum General Administration is the department in charge of preparing and improving the textbooks used in all government schools in Saudi Arabia (AL-Abdulkareem, 2007). Before 1996, the department employed several experts and academic staff to work on the textbooks used for every discipline; these employees

[5] Note that the concept of 'education reform' is not found in the Saudi government literature and its decisions (Aleissa, 2009).

were mostly non-Saudi and were referred to as ‘scientific groups’ (AL-Abdulkareem, 2004). The groups’ role was limited to textbook preparation and did not extend to other components of curriculum design.

Between 1998 and 2001, planning, training and organising groups were established to work alongside the scientific groups. Each of the new groups consisted of a number of experienced teachers in every field and were supported by Saudi university employees (AL-Abdulkareem, 2004; Aleissa, 2009). Theoretically, they were established to support the work conducted by the scientific groups, but no common core role linked the new groups’ tasks to those of the previous ones (AL-Abdulkareem, 2007). The lack of alignment between the groups’ work eventually led to the division of the Curriculum General Administration into two administrative departments: The Textbooks Preparation Administration and the Curriculum Development Administration. Between 2001 and 2004, the Curriculum General Administration launched its initiative to minimise the involvement of the scientific experts and attempted to establish what it called the Comprehensive Curriculum Development Project (CCDP)—an endeavour that failed from the beginning (Aleissa, 2009). The CCDP undertook several simultaneously operated projects, namely, the development of national textbooks, the Secondary Education Development Project (SEDP), the Science and Mathematics Development Project (SMDP) and the teaching of English in primary schools and computer subjects in primary and intermediate schools. These endeavours were assigned to the new groups by the Curriculum General Administration (AL-Abdulkareem, 2004; Aleissa, 2009) and were directed primarily towards secondary schools, with primary and middle school education virtually neglected (Khoja, 1998).

The simultaneous operation of numerous projects under one organisation, the reduction of the scientific groups' role in educational development schemes and the absence of cooperation among the people who worked on these projects engendered weak project outcomes, impeded progress and caused considerable apprehension (Aleissa, 2009; Roy, 1992). The Curriculum General Administration was overwhelmed with the roles that it assumed, thus inspiring a desire to overcome the difficulties that arose during the transformation of the theoretical framework that underpinned the projects into a practical design (AL-Abdulkareem, 2007). The upshot of this situation was that in mid-2004, the organisation was again driven to divide itself, this time into three departments (AL-Abdulkareem, 2007), namely, the Curriculum Development Administration, the Textbooks Preparation Administration and the Teaching and Learning Development Administration. The confusion in distinguishing among the curriculum, intended curriculum and textbook definitions (Aleissa, 2009) led to contradictions in the roles of the Curriculum Development Administration and the Textbooks Preparation Administration. Final products were duplicated given that these divisions developed, prepared and wrote national textbooks separately from the scientific groups (AL-Abdulkareem, 2007). These new groups were tasked to develop Saudi textbooks in accordance with each of their specialisations, intellectual backgrounds, cultural experiences and attitudes and levels of understanding (Aleissa (2009). Their work also revolved around comparing the previous editions of all subject textbooks, incorporating or excluding information from the materials and modifying or replacing certain resources; the groups rarely evaluated the textbooks against the benchmarks for materials development in other countries (Aleissa, 2009).

All these troubles—the contradictions in roles and uncertainties regarding the departments' work—were reported by AL-Abdulkareem (2007), a curriculum and instruction (C&I) specialist, who also established a plan for solving the problems of the Curriculum General Administration. However, his recommendations were disregarded (AL-Abdulkareem, 2007). The failure of the CCDP was attributed by Aleissa (2009) to a number of factors. First, the top officials who were supposed to oversee project operation lacked specialisation. Second, the team did not have a clearly defined vision. Third, the CCDP team worked in isolation and sometimes, in secret, away from the scrutiny of educational institutions, the media, intellectuals and society (Aleissa, 2009). Some of the CCDP team members were considering plans to implement the CCDP as part of a 'machinations plan' meant to serve a certain agenda; apprehension over this possibility led to the abolition of the project (Aleissa, 2009).

To sum up, Saudi Arabia's educational system in general and female education in particular were confronted with numerous changes and difficulties. It is typical for a very young educational system to face such troubles for it to achieve a final product that will provide a better educational system to new generations. The next section discusses one of the Saudi educational system's components—its philosophy.

3.4.3 Saudi Education: Philosophy and Theory

The Saudi educational system seems to be underlain by tenuous support, wherein all its goals and philosophies revolve around the greater umbrella of Islamic morals and values, as clearly stipulated in Saudi educational policy (Aleissa, 2009). The Saudi educational policy document dates back to 1967, providing a brief reference for Saudi education's fundamentals, goals and objectives (UNESCO, 2010). Neither this document nor Saudi educational authorities mention any modern educational theories that may have been used to move the system towards its goals (Al-Ali, 2017). This feature renders the system unresponsive to the landscape changes around it (Tayan, 2017). From its beginnings, the Saudi educational system has been very sensitive regarding the use of philosophy and theories that go against Islamic values (Al-Ghanem, 1999). Such principles have thus been prohibited from use in Saudi curricula, and the adoption of all books has been commandeered from the shelf around the country (Al-Ali, 2017).

This complete break with philosophy, including educational philosophies and theories, left the Saudi educational system without a skeleton that can help align policies and practices with preparation. As can be noticed in the literature, numerous Saudi studies overseas have recently been grounded in educational theories and philosophies given the provision of the King Abdullah Scholarship, which offers students the opportunity to study in different places around the world. However, fear has arisen as to the fact that even when these theories and philosophies have been reviewed and documented, they have not been appropriately applied (AL-Abdulkareem, 2007). Thus, the need to adopt and implement these theories and philosophies in the Saudi educational system is vital as their use is expected to answer many teaching and learning questions that have been left unresolved for decades (Al-Ghanem, 1999). One such question is that related to students' misconceptions.

3.5 Summary

This chapter reviewed the educational landscape in Saudi Arabia, specifically focusing on Saudi female education, which is relatively young compared to the Saudi male education system and other education systems in neighbouring countries. Based on American standards and using traditional teaching and learning techniques (i.e. lecturing), the Saudi education system lacks modern philosophies and theories, thereby producing Saudi education outcomes that fall short of the expectations of decision-makers in Saudi Arabia. Providing a historical review of the Saudi system provides a better picture of female education in Saudi Arabia, the development of education in the case country, Saudi educational authorities, and the Curriculum General Administration. The chapter also examined the language used by the participants of the study and the extent to which thermal concepts are used by these villagers, which may explain why the conceptual change approach may not work for Saudi students and their teachers.

CHAPTER 4
THEORETICAL FRAMEWORK

4.1 Introduction

This chapter exclusively discusses the theoretical framework used in this study which is grounded in the conceptual change approach and mental models. The specific topics covered in the chapter are as follows: Section 4.2 describes the conceptual change approach, Section 4.3 discusses the conceptual change and cognitive conflict, and Section 4.4 gives a brief explanation of how students learn science. Section 4.5 details Chi's (2013) mental models, followed by Section 4.6, which illustrates the Arab cultural model of conceptual change for miscategorisations. Section 4.7 focuses on the fundamental conditions necessary for conceptual change. Section 4.8 discusses conceptual change and misconception, the link between conceptual change and Saudi students' misconceptions, and the existence of thermal misconceptions amongst the study participants. This section also reviews the role of vernaculars in shaping Saudi students' understanding.

4.2 Conceptual Change Approach

The conceptual change approach, which was introduced by Kuhn as early as 1962, provides an explanation of how students learn concepts (Vosniadou, 2013). Kuhn believed that 'science operates within sets of shared believes, assumptions, commitments and practices that constitute paradigms' (Vosniadou, 2013). Thus, existing paradigms cannot accommodate the learning of new phenomena (Posner et al., 1982). Paradigms can be used as a scaffold in a submissive or aggressive manner, superficially or radically in learners' minds, with the end being a paradigm shift

(Özdemir & Clark, 2007). The importance of Kuhn's theory is that it can advance our understanding of the manner by which students construct their knowledge and how these constructions change when they learn about new science concepts and the difficulties that they may face during the process (Vosniadou, 2013). McCloskey (1983) noted that students' minds are full of robust and persistent pre-conceptions, misconceptions and alternative beliefs that resemble old scientific theories (as cited in Vosniadou, 2013). Accordingly, learning new scientific terms such as 'force', 'heat' and 'energy' necessitates that students undergo radical conceptual change (Posner et al., 1982).

4.3 Conceptual Change and Cognitive Conflict

Cognitive conflict is suggested in the 'classical approach' as a pathway to promoting conceptual change during the learning of new concepts, with the role of all sociocultural variables as a driver of individual learning disregarded (Vosniadou, Vamvakoussi, & Skopeliti, 2008). However, Greeno et al. believed that although knowledge is a process that cannot be acquired, developed or changed, it is highly influenced by contextual and situational factors (as cited in Vosniadou et al., 2008). Students seem to lack the ability to apply the knowledge and information learned in school to new situations, particularity to everyday phenomena. The reverse—that is, the transfer of students' prior knowledge to school situations—appears to occur more easily; this phenomenon can exert wide-ranging effects on students' skills, such as reasoning, problem solving, language communication, text comprehension and new knowledge acquisition (Vosniadou et al., 2008). In this regard, Vosniadou (2013) contended that many science concepts are challenging to learn because knowledge acquired under everyday settings is embedded in framework theories (prior knowledge) that are constructed by students for use as explanatory frameworks. In contrast, knowledge acquired under school settings is embedded in a radical framework that renders such know-how somehow unrelated to prior knowledge. In this situation, school-acquired knowledge is incorporated as an additive or enrichment mechanism into what is already known through everyday settings. Between the two contexts, students develop synthetic models (misconceptions) as a result of the implicit use of the additive learning mechanisms in events where new knowledge belongs to an explanatory framework that differs from that of prior knowledge (Vosniadou et al., 2008).

4.4 How Students Learn Science

Considering Kuhn's point of view, the learning of science and its concepts goes through two phases of conceptual change. In the first phase, central commitments are responsible for defining problems, indicating strategies and specifying what may be considered solutions. Lakatos described this phase as the generation of 'research programs'. In the second phase, the modification of central commitments is necessary, thus also requiring changes to research programs (as cited in Posner et al., 1982). Posner et al. (1982) reimagined Kuhn's two conceptual phases of learning science as assimilation and accommodation. Assimilation happens when students need to learn about new phenomena, for which they normally use existing concepts as an avenue for comprehension. Accommodation occurs when students struggle to grasp a new phenomenon successfully because currently existing concepts are inadequate for them to accomplish understanding. In this case, central concepts must be replaced or reorganised and play a vital role in new learning. Without such concepts, students find it difficult to inquire into phenomena to know what would count as a solution to a question or to determine what features of phenomena are relevant and which are not (Posner et al., 1982). To improve students' understanding through the promotion of conceptual change, Posner et al. suggested that 'any available metaphors, models, and analogies should be used to make a new conception more intelligible and plausible' (Posner et al., 1982, p. 225).

In sum, Kuhn's conceptual change approach has been discussed as related to students' misconceptions (Vosniadou, 2013). The section also recounts how students learn science as explained by Posner et al. (1982). The succeeding section focuses on mental models and how students learn new concepts, replace old ones, fill incomplete concepts and develop misconceptions, as related by Chi (2008). The author stated that the effects of existing mental models are essential for conceptual change as the possible absence of such models can lead to lack of knowledge, which can inadvertently be interpreted as misconceptions. By reviewing these models, the study intends to find the category that best explains Saudi students' errors in the Thermal Concepts Evaluation.

4.5 Types of Prior Knowledge Mental Models

Lin and Chen (2010) defined a mental model as a description of individuals' thought processes regarding how things work in the real world. From the authors' perspective, a mental model is a necessary approach in solving problems and completing tasks. It can also be defined as comprising internal symbols and representing external reality, which have been hypothesised as supportive principles for cognition, reasoning and decision-making processes (Lin & Chen, 2010). Gentner and Stevens described a mental model as the internal representation of a concept or the node of concepts that are interrelated and represent an external structure (as cited in Chi, 2013).

Chi (2013) explained that when concepts are ‘to-be-learned’, students have some prior but incomplete knowledge about these ideas, and this prior knowledge can be used to fill the gap left by knowledge that has yet to be acquired even though it may also conflict with ‘to-be-learned’ materials. The problem with the gap-filling mental model is that it does not stimulate conceptual change formation, which result on no trigger such change. Concepts that conflict with ‘to-be-learned’ ideas are called misconceived knowledge. Conflicting concepts are considered ‘misconceived’ rather than ‘incorrect’, with the former referring to ideas that are constantly resistant to change and the latter being ideas that are not always resistant (Chi, 2013). Chi (2013) identified four sub-dimensions of misconceived knowledge that contradict the normative ‘correct model’ which is in line with modern scientific theories: false beliefs, flawed mental models, category mistakes and missing schemas.

4.5.1 False Beliefs

One way that naïve beliefs can contradict the normative correct model is that if they are false (Chi, 2013). Naïve beliefs are regarded as false beliefs when they are inaccurate and can be refuted with correct information in the same dimension. An example of a false belief is ‘the heart oxygenates blood’ (Chi, 2013, p. 51). Such beliefs can be resolved by refuting, replacing or simply ignoring them. The refutation can be explicit (direct) or implicit (Duit et al., 2008). An example of explicit refutation is ‘the heart does not oxygenate blood’, and an example of implicit refutation is ‘the lungs oxygenate blood’ (Chi, 2013, p. 51).

4.5.2 Flawed Mental Models

Another way that naïve beliefs can contradict the normative correct model is if they are flawed beliefs. In a flawed mental model, the cores of the nodes of incorrect concepts are coherent and do not contradict one another (Chi, 2013). The model is an incorrect naïve model that is characterised by a coherent structure and consistent pattern of predictions and explanations in response to a variety of questions. An example of a flawed mental model is the consideration of the human circulatory system as a single loop (Chi, 2013). Another example is imagining the earth as a flattened disk (Chi, 2013). The flawed mental model conflicts with the correct model in that both involve the same assumptions yet generate different predictions. The flawed mental model can be treated almost easily through explicit or implicit contradictions in formal schooling (Chi, 2013).

4.5.3 Category Mistakes

Some misconceptions are known for their robustness against change. Physics misconceptions, such as those related to 'force and motion' and 'heat and temperature', have been reported in many studies as resistant to change (Chi, 2013). Such robustness was attributed by researchers to the challenge of attempting conceptual understanding in the presence of misconceptions (Chi, 2013). Conversely, Chi (2013) believed that the robustness of these misconceptions is due to the miscategorisation of a concept to an inappropriate lateral branch (schema) that is hierarchically unrelated to the branch to which the concept belongs. Thus, a concept must be associated with a parallel category. For conceptual change to occur between two lateral categories that are in conflict in terms of definitions of kind and/or ontology, a concept should shift across the two lateral categories (Chi, 2013). Concepts in two lateral categories are perceived by students as entities when in reality, they constitute processes. For instance, 'hot molecules' and 'hot stuff' are described by students as the entities of heat, but the correct description of these concepts is that they are the processes of the 'speed of molecules' (Chi, 2013, p. 57). This entity-oriented perception applies to other science concepts, such as force, electricity and light. The entity and process models of concepts have no common dimensions (Chi, 2013), and this type of ontologically miscategorised misconceptions are extremely resistant to change. Thus, formal schooling and direct contradiction appear to be ineffective means of recovering the ideas that prior knowledge has taken over and correcting perspectives that have dominated students' explanations and understanding (Chi, 2013). For instance, adding more detail to the concept of force, such as the equation 'F = ma', will not advance the understanding of the concept or overcome the misconceptions linked to it (Chi (2013). The only way to resolve ontologically miscategorised misconceptions is through a categorical shift, wherein a concept is shifted across or reassigned between two lateral/ontological categories. Chi (2013) suggested two conditions in which these misconceptions can be shifted: awareness of an issue and awareness of a correct category.

4.5.4 Missing Schemas

To shift the category of a misconception that is mistakenly allocated to a lateral category, students must be aware of such issue and its solution (Chi, 2013). If students lack awareness, then misconceptions become tenaciously robust (Chi, 2013). The errors originating from this lack of awareness engenders new levels of misconceptions that are neither false beliefs nor flawed mental models given that they do not occupy the same dimensions. Thus, they cannot be changed through explicit or implicit refutation possibly because some of the misconceptions that are regarded as belonging to the process category fall under two other sub-categories: sequential and emergent (Chi, 2013).

The difference between sequential and emergent processes is that the latter have no identifiable causal agent/s or identifiable sequence of events (Chi, 2013). A sequential misconception requires direct causal explanation, whereas an emergent misconception needs an emergent causal explanation. An example of a sequential process is cell division, wherein posterior events cannot occur until anterior ones are completed (Chi, 2013). An example of an emergent process is gas exchange in the lungs through diffusion, which involves a random movement of oxygen and carbon dioxide molecules in both sides of the membrane between the alveoli and the capillaries (blood vessels) that envelop them. However, the overall movement suggests that more oxygen molecules move towards the capillaries from the alveoli because there is more oxygen in the latter than in the former; more carbon dioxide molecules move from the capillaries towards the alveoli because there is more carbon dioxide in the former than in the latter (Chi, 2013). In the same sense, Chi (2013) categorised diffusion and natural selection as emergent processes even though at first glance, no common thread exists between these processes. The author found commonality in the second-order interaction features of the processes—uniformity. Thus, diffusion and natural selection fall under the same emergent category. Unfortunately, students cannot independently discriminate between sequential and emergent process schemas. Initially, students are assumed to have no knowledge of an emergent category (ignorant) to which most of new processes in science belong (Chi, 2013); emergent knowledge includes know-how on cell division, diffusion, natural selection and heat transfer. The missing schema of emergent concepts and phenomena would be constructed by creating an alternative schema that has the properties of an emergent schema that is distinct from the direct schema of sequential processes. By creating the alternative schema, students will have something to build on and assimilate new instruction (Chi, 2013).

To sum up, Chi (2013) found two types of misconceived mental models, which give an access to understanding how new concepts operated by students during their learning, as well as why some ideas are resistant to change. In Arabian culture, Arabs do have a way of resolving one type of misconceived knowledge discussed by Chi (2013) that is ‘Category mistakes’.

4.6 Arab Cultural Model of Conceptual Change for Miscategorisations

Ancient Arabian narratives show a trick which used to correct learners’ misconceptions about concepts that do not fit with the rest of the ideas that belong to a given branch. The trick involves shifting the category of the concept that is mistakenly categorised by students and reassigning it to a new temporary category known as an ‘alternative category’. Thus, students will not mistakenly categorise the concept to its old category because they already reassigned it to a different new mental model that keeps the miscategorised concept as far away from its miscategorised branch. This alternative mental model can be used to correct the mistaken categorisation evident in ‘whale/fish’, which is considered one of the most common misconnections performed by students of every school age level (McCoy, 1983, 1987).

Old Arabian narratives indicated a new category to which whale could be assigned, recounting that whales used to refer to women who did not obey their husbands (Al-Ghannam, 2010) and were thus banished by God and turned into whales. In re-reading this trick, it can be seen that whales were represented as women (mammals) to indicate that the former have mammalian features, such as giving birth to a live young, breastfeeding, having the same temperature as that of a human (37°C) and most importantly, breathing through lungs instead of gills. Thus, it is not a fish because it is a metamorphosed being (alternative category). Even though this explanation deviates considerably from an account based on modern science, it promotes the discarding of superstitions, and it sounds very sensible and successful if used in a correct manner. The application of such 'independent' temporary categories in Arabian narratives may be ascribed to the lack of precise taxonomies in early times. Nevertheless, the tales exhibit a clever strategy for overcoming the taxonomy problem through reassignments to alternative categories. This practice was called by Vosniadou (2008) as 'bridging' for situations wherein language capacity is insufficient to deliver ideas or models. The taxonomy of the animal kingdom was formulated by Carl von Linné around 1730 (MacLeod, 2007); thus, terminology such as 'mammals' could not be found in the Arabian literature before the modern scientific revolution.

Another example of the Arabian narrative strategy is the description of a bat as a man that stole others' properties and was therefore banished and turned into the animal. In this case, the mental model that regards a bat as a bird is destroyed completely through the reassignment of the bat in the mammal category via the alternative category of metamorphosis. This trick worked for hundreds of years before the advent of modern science, even though such tales have been called superstitions. To date, students at every school level still experience confusion over concepts such a 'whale is not a fish' (Read, 2004); using such a trick may overcome this confusion. The validity of these examples as explanations was supported by Vosniadou (2008), who stated that some misconceptions are 'indeed not non-sense, that they usually make perfect sense' (p. 278).

To recapitulate, students' misconceptions and errors do not exhibit the same levels of conflict with correct concepts or phenomena. Some prior knowledge ideas conflict with correct concepts in terms of accuracy, whereas others conflict in terms of commensurateness. In the latter, students struggle to differentiate between entity-based concepts (heat/temperature) and process concepts. Process concepts themselves belong to different categories: emergent (e.g. state change, evolution) and sequential (e.g. procedures, events). Creating a schema that is missing because of ignorance of related information can help students understand new concepts. This section also has described the old Arabian cultural model of shifting concepts between two mental models. Next, the fundamental conditions for conceptual change set by Posner et al. (1982) and the creation of a satisfaction matrix are discussed.

4.7 Fundamental Conditions Necessary for Conceptual Change

The classical approach of the conceptual change theoretical framework is framed by fundamental conditions that must be satisfied by students before any conceptual change can happen (Duit et al., 2008). First, dissatisfaction with old concepts must transpire, and second, new concepts must be intelligible, plausible and promised (favourable) (Posner et al., 1982). Posner et al. (1982) also pointed out the role of cognitive conflict in producing conceptual change within the classical approach.

Duit et al. (2008) suggests that, three levels of dissatisfaction with old concepts (schema) may generate three different scenarios: First, if a new concept to be learned does not generate enough dissatisfaction with a previous concept, then the old concept will assimilate the new one alongside it. Second, if two concepts (old and new) have the same level of satisfaction/dissatisfaction, then two conceptual events can happen. Third, if satisfaction with new concepts is very high, then these ideas will take over old ones (accommodation). The last scenario constitutes conceptual change. The satisfaction trigger level necessary for conceptual change, as explained by Duit et al. (2008) is illustrated in Table 4.1

Table 4.1 *Possible results of competition between new and old schema*

Dissatisfaction of old schema	Satisfaction of new schema	Conceptual change	Result
Low	Low	No	Assimilation
Low	High	No	Equilibration
High	Low	No	Equilibration
High	High	Yes	Accommodation

Table 4.1 can be simply summarized using the matrixes shown in **Table 4.2** - Table 4.5, which explain the levels of satisfaction with old concepts (schema) and new concepts. Only one case out of four, triggers conceptual change. Posner et al. (1982) recommended measuring the level of dissatisfaction with an old concept against the level of satisfaction with a new concept, and Duit et al. (2008) adhered to this suggestion. However, there were no differences between measurements of satisfaction/dissatisfaction with old and new concepts. All such measurements yield the same results, and the decision regarding which ones to use depends on a researcher's preferences. Note that a high dissatisfaction level logically corresponds to a low satisfaction level and vice versa. The same matrix can be generated individually for intelligibility, plausibility and fruitfulness.

Table 4.2 illustrates that by using satisfaction level of the old and the new schema as an indicator, there is only one case that can triggers conceptual change to occur. This trigger point case labelled as *yes* in the **Table 4.2**, and it says if the satisfaction level of the old schema is very low and the satisfaction level of the new schema is very high, then it's more likely to conceptual change to occur.

Table 4.2
Satisfaction's matrix

		New schema	
	Satisfaction level	Low	High
Old schema	Low	No	Yes
	High	No	No

In addition, Table 4.3 shows that the possibility of using dissatisfaction level of the old and the new schema as an indicator. In order to conceptual change to occur the dissatisfaction level of the old schema must be at its highest point, and the dissatisfaction level of the new schema must be at its lowest point. In this case, the trigger point also labelled as *Yes* in Table 4.3.

Table 4.3 *Dissatisfaction's matrix*

		New schema	
	Dissatisfaction level	Low	High
Old schema	Low	No	No
	High	Yes	No

On the other hand, the satisfaction of the new schema and dissatisfaction of the old one level can by use as adjoin to trigger the conceptual change. In this case, both satisfaction of the new schema and dissatisfaction of the old schema must be at their highest level. Table 4.4 illustrates this case.

Table 4.4 *Satisfaction/ dissatisfaction matrix*

		New schema	
	Satisfaction/ Dissatisfaction level	Low	High
Old schema	Low	No	No
	High	No	Yes

Similar to previous case, the dissatisfaction of the new schema and satisfaction of the old schema level can be used to locate the trigger point of conceptual change to happen (see Table 4.5). Conceptual change could happen if both dissatisfaction of the new schema and satisfaction of the old schema must be at their lowest level.

Table 4.5 *Dissatisfaction/ satisfaction matrix*

		New schema	
	Dissatisfaction/ Satisfaction level	Low	High
Old schema	Low	Yes	No
	High	No	No

In brief, for conceptual change to happen, two conditions must be met: dissatisfaction with an old concept and high satisfaction with new concept due to its intelligibility, plausibility and fruitfulness. Duit et al. (2008) suggested two scenarios that can occur from the competition between old and new concept and indicated that such occurrence depends on the level of satisfaction. The next section discusses three examples of Duit et al. (2008) satisfactions scenarios in the Saudi context.

4.7.1 Accommodation Scenario

The Arabic language has three formats: Colloquial Vernacular (native) Arabic, Classical Arabic (emerging in the 7th century) and Modern Standard Arabic MSA (emerging in the 19th century) (Shah, 2008). Some Saudi vernaculars are very primitive and belong to an old dead language but are still used and understood by a small group of people (Rubin, 2012). Modern Standard Arabic is the latest standardized version of Classical Arabic language used to facilitate modern communication, administration and education. It is described as a plain or 'white' dialect because it is understood by everyone and belongs to no one (Elgibali & Badawi, 1996; Shah, 2008; Shohamy, 2010).

For Saudi people who were suddenly awoken from almost complete ignorance in 1932, during which the new Saudi kingdom arose, numerous things were available for learning. One of these things was the newly established Modern Standard Arabic, which developed through both the displacement and replacement of native Arabic languages. Because of a language barrier, students who live in harsh environments with limited resources and diversity and who speak vernacular native languages that are characterised by minimal vocabulary content appear to experience difficulties in applying what they learn in school to phenomena that they encounter in their daily lives (Al-Sukkari, 2014). Most thermal physics terms and majority of the terms in the Periodic Table, for instance, are not found in vernacular Arabic. Add, because thousands of vocabulary items were added to Modern Standard Arabic (Elgibali & Badawi, 1996), many new concepts and terms have no equivalent in people’s everyday language.

Sometimes, Modern Standard Arabic borrows certain terms from Classical Arabic, even when meanings do not match and only as long as a borrowed term is closest to its English equivalent. An example is ‘atom’, which does not exist in the Arabian language and was translated to *darah*, which means ‘ant’ in old Arabian dictionaries. Both *darah* and ‘ant’ are mentioned in the holy book of Islam.

Arabian people used to believe that an ‘ant’ is the smallest object for whom weight can be measured. Given that ‘ant and *darah* are ascribed the same meaning, translators worked to empty one term of its ‘entity’ and classified the two terms under different mental branches to prevent people from confusing them. The term that was emptied of its soul was *darah*, which no longer means ‘ant’. In the next stage, they loaned the emptied term to Modern Standard Arabic language to denote the ‘atom’ of the English language and classified it at the end of the lowest branches of the entity-based mental category. As can be seen in Chi's (2013) distinct ontological tree chart, 'ant' was categorised under 'living beings', which occupies a higher branch of the entity-based mental category. The two terms thus belong to different category levels.

As previously stated, applying satisfaction matrix of trigger point for conceptual change enables an understanding of how conceptual change occurs in this case (see Table **4.2**). The level of satisfaction of users with the old concept/meaning turned out to be very low, discovering that 'ant' is not the smallest object in the wold. The study of chemistry and physics plays a role here. Conversely, users' level of satisfaction with the new concept/meaning was very high because the use of *darah* to mean 'atom' indicates that the atom has been mentioned in the holy book for over 1500 years, which is a miracle[6]. This discovery was the trigger of satisfaction.

The whale/fish example ended with a conceptual change because of the shift in the whale category into an alternative category, whereas the atom/ant example drove conceptual change because of the satisfaction level triggered by the increase in usage of one term over the other. Posner et al. (1982) and Hewson (1982) argued that a student is the main player in conceptual change; the decision to accept or reject such change is in the hands of the student (as cited in Duit et al., 2008). The whale/fish and atom/ant situations suggested that intentional well-designed instruction can facilitate conceptual change. These examples also remind us of the strength of sociocultural factors in delivering conceptual change to individual minds (Vosniadou, 2008).

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[6] Now, the 'atom' term appears in all English translation versions of the holy book, while there are no change in the old versions. See for example the version translated by Sale (1838).

4.7.2 Assimilation Scenario

If satisfaction with an old schema is higher than that with a new concept, the latter will be assimilated by the former because it failed to generate the satisfaction necessary to encourage individuals to believe in it and discard previously formed ideas (Duit et al., 2008). A new concept that fails to gain credibility over an old idea because it is unintelligible, implausible, unfruitful or unable to manipulate satisfaction/dissatisfaction must be rejected. Studies showed that every concept has to go through a student's judgment (Hewson, 1982; Posner et al., 1982), who decides whether a new concept is intelligible, plausible or fruitful for him/her. These studies also indicated that a new concept is sometimes assimilated into a persistent old concept, demonstrating that the new idea is flawed.

A case of assimilation can be illustrated by the World Health Organization's (2017) discovery of a link between the recently reported multiple deaths in Saudi Arabia caused by the Middle East Respiratory Syndrome Coronavirus (MERS-CoV) and the camels in the country. To date, however, Saudis continue to consume camel milk, meat and urine as part of cultural and religious beliefs, despite the efforts of the Saudi Health Department, schools and social media to convince people to stop consuming these products. Saudis may have deemed information regarding the association between MERS-CoV and camel products insufficiently satisfactory to stimulate dissatisfaction with the Saudi camel market, which is considered one of the largest industries in Saudi Arabia. In this case, satisfaction with the business is at the highest level, whereas satisfaction with the link between the virus and camels is at the lowest level. As indicated in satisfaction matrix (see Table **4.2**), the Saudis assimilated new information and strengthened the old schema by increasing advertising about the camel festival year-round.

4.7.3 Equilibration Scenario

Table 4.1 identifies two sub-scenarios under equilibration, wherein two competing concepts trigger the same level of satisfaction/dissatisfaction, and students alternate between the two concepts to serve their own desired benefits. These scenarios, in which points of satisfaction are unsatisfied, is where misconceptions come from. Multiple attempts that fail to accommodate students' misconceptions may increase or strengthen such notions. The case of Saudi mothers who ask for antibiotics as a cure for their children's flu as an example. In the past, hospitals used to administer antibiotics as a treatment for the illness, despite the Saudi Health Department's initiative to educate people about this misconception. To date, people still resort to this form of intervention in treating the flu (Nafisah et al., 2017). Some Saudi mothers may have regarded the information on antibiotics as unsatisfactory and prefer to continue using it as long as no other effective treatment is provided. According to the matrix of trigger points for satisfaction (see Table **4.2**), conceptual change happens when satisfaction with an old concept is relegated to a low state, and a new concept is positioned at the maximum point, thus paving the way for the replacement of the old schema. The aforementioned case is one of equilibration and may persist until a new treatment is discovered.

To sum up, the conceptual change satisfaction matrix was created and used in this section to interpret three cases observed in the Saudi context. The examples revealed underlying social factors that may interrupt the occurrence of conceptual change in learning scientific concepts. All the cases involved a certain degree of conceptual change, but the desire for such change and, ultimately, the contemporary conceptual change that is consistent with modern scientific theories are at the hands of educators. In what follows, a review of how the failure of the conceptual change approach, may lead to the formation of students' misconceptions in many disciplines.

4.8 Conceptual Change and Students' Misconceptions

Kuhn's classical approach seems applicable to every single concept that students come across, but Vosniadou (2013) declared that students' brains are very selective, driving them to select only the additive and enriching concepts that produce conceptual change. Vosniadou et al. (2008) and Inagaki and Hatano (2008) differentiated between 'spontaneous' conceptual change as a part of cognitive development and 'instruction-induced' conceptual change as part of the instructional process. The latter is more likely to cause the formation of misconceptions (Vosniadou, 2013). Duit et al. (2008) pointed out, however, that most teachers are unaware of conceptual change issues or the instructional strategies recommended for solving them.

Disessa (1988) emphasised the importance of designing a curriculum on the basis of conceptual change and model-based reasoning strategies in helping learners build basic prior knowledge that enables them to understand advanced scientific knowledge. The author further suggested the use of constructive methods that expose students to practical experience of conceptual change through the provision of more examples (as cited in Vosniadou, 2013). The lack of conceptual change can be the main cause of the widespread failure in science and mathematics among students (Vosniadou, 2013); such a lack conceptual change may prevent critical thinking and result in fragmented knowledge, thereby producing a cognitive conflict between 'to-be-learned' information and 'experience-based' lay knowledge (Vosniadou et al., 2008).

The satisfaction matrix, on the other hand, suggested that more misconceptions than successful notions can likely occur during the conceptual change process by a ratio of 1:3 (Table **4.2**). In other words, there is one chance that an old schema will be modified against three chances that it will not. In a scenario wherein conceptual change successfully occurs, the old schema is replaced or the new concept is used more frequently than the old schema (Duit et al., 2008). Consequently, the old schema gradually atrophies, freezes or becomes inactive for many years (Perhaps for many generations) (Posner et al., 1982). Until a new trigger point emerges, the old schema will not be revived. Examples of new trigger points are new evidence found during personal research, scientific approval of a new idea or religious interest. On the basis of contemporary normative standards, the old schema will be evaluated by students as incorrect (Chi, 2013). As previously described, three scenarios can emerge during the conceptual change process: assimilation, equilibration and accommodation (Duit et al., 2008). However, the satisfaction level is only a matter of degree; theoretically, the scenarios that may emerge during conceptual change are unlimited because there are equally unlimited satisfaction levels between high and low levels. The number of scenarios depends on each individual's skills, level of education, level of knowledge and level of interest.

Even the concept of intelligibility is a matter of degree. What may be intelligible to someone under an exciting setting may not be intriguing under a different setting. What may be considered plausible by a group of people may not be regarded in the same way by others. The same holds for fruitfulness. An example is the provision of the right to drive for women in Saudi Arabia—an initiative that spanned generations before it was implemented. Even with the obvious fruitful, plausible and intelligible benefits of having women drivers, it took a long time to bring this vision to reality and may take equally long to see more women on the road because of cultural barriers. There is nothing wrong with Saudi women choosing not to drive just as there is nothing wrong with American women choosing to drive, but these situations may be considered wrong from the perspective of Saudi society. Changing a society's perspective towards a phenomenon necessitates instructed conceptual change plans that take sociocultural factors into account. This is exactly what Duit et al. (2008) meant when they stated that conceptual change corresponds to 'context-driven choices' (p.6). This may also explain why the same instructions yield different results under different contexts.

In summary, the conceptual change approach has achieved widely successful results in changing students' misconceptions under different contexts and disciplines (Duit & Treagust, 2003). However, the approach does not consider the absence of fundamental skills, such as critical thinking, reasoning and problem solving (Vosniadou et al., 2008); individuals' levels of education, knowledge and interest; the combination of sociocultural factors and communication barriers (Vosniadou, 2008); the nature of scientific materials; and teachers' lack of familiarity with the approach (Duit et al., 2008). Together, these additional factors can render the modification of students' misconceptions a difficult instructional operation. The following section deals with examples of conceptual change processes that may drive the formation of misconceptions among Saudi high school students.

4.8.1 Conceptual Change and Saudi Students' Misconceptions

Every culture has its own unique misconception schemas that differ from those of other cultures. People build knowledge to survive and pass their experiences from one generation to another. Survival factors, such as language, knowledge, food security, art, medicine and wisdom, drive individuals to recycle their knowledge to their peers. For instance, even though we live in modern societies, traditional medicine industries all over the world remain very strong. Survival factors are part of the sociocultural net. Thus, every culture develops its own conceptions that, when unaligned with modern scientific ideas, may appear contradictory to one another. The fish/whale model discussed earlier is a case in point. Stating that a whale used to be a woman may be regarded as absolutely wrong from a modern scientific standpoint, but such explanation is absolutely sensible from the perspective of old Arabian narratives. Every culture uses different tools to interpret the same phenomenon (Kashgary, 2011).

The temperature/heat intensity issue can be explained in a similar manner as the atom/ant matter (Section 4.7.2). Due to the non-equivalence between the English and Arabic languages, there are more terms regarding one subject in one language than in the other (Kashgary, 2011). As described earlier, this situation compelled translators to empty one term of its meaning to use it as a denotation of another term that has no equivalent in Arabic. The closest synonym of 'temperature' in Spoken Arabic Vernaculars is 'heat intensity', but 'intensity' is reserved for another physics concept in Modern Standard Arabic. It served as a borrowed term to refer to new expressions that have no equivalent in Arabic, such as magnetic field intensity, electrical intensity and light intensity. In return, Modern Standard Arabic ascribed the phrase 'heat degree' to an object's temperature—an *unfortunate* term given that it refers to an object's level of hotness and not to molecular speed. Satisfaction with the loaning of the old term 'intensity' to another term was very high, and so was satisfaction with the use of the new term 'heat degree' instead of 'heat intensity' to refer to 'temperature' in Modern Standard Arabic.

As shown in the satisfaction matrix (see Table **4.2**), if both old and new concepts stimulate the same level of satisfaction, then no competition occurs and equilibration transpires (see Table 4.1). The concepts will be used alternately, depending on context. Accordingly, 'heat intensity' is used more often in everyday context, whereas 'heat degree' is used more frequently in school and in the media as a formal term[7]. At the same time, 'magnetic field intensity', 'electrical intensity' and 'light intensity' are used formal, whereas 'intensity' is sometimes used to refer to 'strength' in everyday Arabic language. 'Heat intensity' is a very old term that mostly pertains to a very high level of temperature. This non-existent term is equivalent to 'temperature' in everyday Arabic language and may be the source of confusion of students over it; using 'heat degree' seems to reinforce the misconception that 'temperature' is an object's level of hotness. This complicated situation arose from the conceptual change process that is linked to the translation from English to Arabic—a translation that was prompted by untranslatability or non-equivalence between the two languages. Thus, translators implemented a borrow/ loan strategy, wherein some terms were loaned to denote a meaning that differs from what people are accustomed to (Kashgary, 2011). On the other hand, vernaculars developed the term 'heat intensity' to refer to a wide range of temperature, not only very high ones, to mimic the term 'temperature' in science and to overwhelming (so to speak) the term 'heat degree' in Modern Standard Arabic. As a result, 'heat degree' is used mostly in textbooks, and 'heat intensity' is used mostly outside school.

Another case is the well-known misconception 'heat rises', which has never been heard (at least) among the locals of the Eastern Province of Saudi Arabia. A very

[7] Because of the power of the media, the number of people who use the term 'heat degree' increased gradually.

common expression is ‘hot air rises’, which is a very old expression and serves as the principle behind the manufacture of *barajeel* or ‘airways’, which function similar to air-conditioning these days and continue to reflect Dubai’s heritage (Elmasry, 2017). For students to understand unfamiliar concepts, satisfaction with these terms/expressions has to go through two barriers: the scientific nature of physics terms and Modern Standard Arabic, which restricts the use of such terms to school settings. This non-familiarity with some fundamental scientific concepts and the non-use of modern standard Arabic language that serves as a medium for delivering modern Western science may have contributed to the failure to trigger the satisfaction of students. Hence this situation may have provided opportunities for misconceptions to form and a lack of knowledge to persist. These, in turn, prevented conceptual change from occurring, as suggested in the satisfaction matrix.

To sum up, the conceptual change approach is a powerful tool that is used to align people’s perspectives with modern scientific viewpoints, but failure to satisfy all the conditions necessary for change may lead to the formation of misconceptions (Vosniadou et al., 2008). Failed conceptual change may not only drive the modification of one concept into another in the same language but also magnify such modification when applied to different languages through the translation process. Saudi students, for instance, are compelled to deal with multiple conceptual changes at different levels at once: vernacular, Modern Standard Arabic and scientific language. Switching between the vernaculars of every group of students (perhaps every single student) and Modern Standard Arabic in the same class may make conceptual change more difficult to process through only traditional teaching and learning approaches. In this situation, students will have to discard the meanings of the concepts that they grew up knowing, loan them to different concepts within school walls and then switch back to the previous meanings whenever they leave school. The problem, as a group of Arabic experts indicated, is that Modern Standard Arabic is spoken by almost no one outside the educational realm and the media (Almajma, 2017).

The next section reviews the thermal concepts used by the current research participants in their everyday language. It focuses on vernaculars and conceptual change as well as on the lack of diversity in the everyday thermal concept language of the Saudi students.

4.8.2 Conceptual Change in Thermal Concept Understanding among the Study Participants

For centuries, people in the Arabian Peninsula where the Kingdom of Saudi Arabia is located lived without almost no education and were ruled by ignorance and poverty (Murtada, 1996). During this time, individuals developed basic knowledge that helped them survive harsh environmental conditions. People who lived near the coast developed minimum knowledge about seas, oceans and weather. For these people, the sea was a huge concern because traversing it entails a considerable amount of time. People (especially women) learned to set fire on beaches so that boats could find their way home. However, the fire that brought hope and life to the villagers also brought death. In 1910, my village was destroyed completely after a fire that was set near the beach to guide boats, blazed out of control, killing numerous individuals, mostly women and children, and leaving hundreds without shelter. The incident also forced many to immigrate to neighbouring countries. The only surviving building was the mosque, which was made of bricks; the rest of the village structures were made from palm fronds[8]. This scenario happened frequently in the past: boats could not find their way home without help from villagers, and villagers could not control fires (Al-Taee, 2005). I was told by my elders that the word most frequently used by people in these villages in their everyday lives to describe almost anything that causes them discomfort is ‘fire’. They even teach babies and toddlers to say ‘fire’ when they cry (see Table 4.6). These expressions are part of people’s intellectual environment and continue to be used to this day. Out of the 59 statements linked to heat that have reviewed, 23 express good feelings, 32 denote bad feelings and the remaining four indicate neither direction. This finding is similar to that of Hewson and Hamlyn (1984), who stated that people in Africa use the word ‘heat’ to refer to bad feelings and the word ’cold’ to refer to good feelings.

[8] My great grandfather was the only person in his entire family to survive. He was 4 years old, and a man found and hid him inside a small boat to protect him from the fire.

Table 4.6 *Lists of some heat-related expressions that gathered from people in the villages where this study was conducted*

Good expressions	
1.Fire = What a surprise.	2.Her blood is hot = She will reach puberty very early.
3.The water is hot.	4.He set them on fire. = Make them happy/excited
5.The coal is hot.	6.Does your phone have a heat? = Does it have credits to make calls?
7.The fire is hot.	8.Hope God cools your heart = Hope you get good news soon
9.The frying pan is hot.	10.Their wedding was hot. = Very exciting
11.The knife is hot. = Sharp	12.Their funeral was hot. = They were mourning loudly.
13.Warm it up. = Heat it up.	14.He made me boil. = He's made me impatient to hear the news.
15.Warm up the soup. = Heat it up	16.Cool down my heart's fire. = Let me know about your news.
17.Hit the iron when it's hot.	19.Burn them/set them on fire. = Beat them.
18.Bring the tea refrigerator with you.	20.Hot by hot = Do it as soon as possible
21.Very hot speech = Very good speech	
Bad expressions	
1.My Dad is hot= Very strict	2.He set us on fire. = He did not give us breaks and makes us work hard.
3.My Dad is fire = Very strict	4.My heart boils for him. = Very worried
5.Fire! = What the hell	6.He made me boil. = He made me suffer.
7.Use a heat antipyretic.	8.The air is ice. = The weather is cold.
9.His body is fire. = Fever	10.Close the door so that heat doesn't come in.
11.Boiled bubbling. = He is very mad.	12.What's wrong with him a fire? = Very angry person
13.She is boiling = She is mad/angry.	14.I don't have any force. = Don't have any energy
15.Their price is fire. = Very expensive	16.They burnt us by their eyes. = Envious
17.My child's heat is very high.	18.Her eye is hot/fire. = She is glaring at us and jinxing us.
19.His body is boiling. = Fever	20.He melted my heart. = It was hard to raise him/convince him.
21.Her child birth was hot. = Painful	22.Fire doesn't burn the feet of those which don't step on it. = They don't feel what we feel.
23.He is boiling. = Waiting impatiently	24.We heated the water, and the chicken flew away= We were prepared for something that never came.

These expressions suggest that the villagers developed minimal vocabulary in their vernaculars for expressing feelings and describing people or processes. All these expressions revolve around the word ‘fire’. As shown in the list, the villagers conceive of hotness at five levels, namely, cold, cool, warm, hot and lukewarm (Kashgary, 2011), which refer to heat intensity/degree/level. Most of the time, the villagers describe different temperatures using the same word, namely, ‘hot’ because the concept of temperature does not exist as a specific term in their language. Distinction between expressions depends on the receiver. For instance, they say ‘the water is hot; the frying pan is hot; the coal is hot; and the fire is hot’, regardless of the meaning that they intend to convey. From their perspective, however, the statement ‘water is hot’ differs from the statement ‘tea is hot’. The first mostly means warm, whereas the second means hot.

To date, the majority of these villagers use the phrase ‘heat stick’ to refer to a thermometer, whose use is limited to the measurement of body temperature (medical thermometer). It is a foreign device to these people because the term ‘thermometer’ does not have an equivalent in their language. Thus, they use the English term ‘thermometer’ at school and ‘heat stick’ in everyday language. The term ‘heat stick’ emerges in the Spoken Arabic Vernacular of these people as a means of addressing the absence of the term in their language and overwhelming Modern Standard Arabic, which uses the English term. It seems, all along, that there are two translations of English terms: one prescribed by Modern Standard Arabic supporters and another advocated by vernacular Arabic supporters.

Despite the existence of Modern Standard Arabic, the addition of new words/expressions to Spoken Arabic Vernaculars does not accord most of the time with any rules, apart from acceptance from users (Hallberg, 2016; Shah, 2008). By contrast, the addition of words/expressions to Modern Standard Arabic necessarily requires following rules on grammar and sentence structure. This adherence is most important in guaranteeing confirmation from language institutions regarding the addition of a word or its rejection. Incorporating new words into Modern Standard Arabic is therefore a very slow process, whereas such task for vernacular Arabic proceeds quickly. Correspondingly, vernacular Arabic grows faster and stronger than does Modern Standard Arabic given the blessing of high satisfaction enjoyed by the former. In this situation, vernacular Arabic seems to have power over conceptual change. This is an unsurprising development; according's to level of satisfaction matrix (see Table **4.2**), the possibility of an old schema dominating over conceptual change is higher than that of a new one. Nevertheless, vernacular Arabic provides simpler terms and more superficial interpretations than that found in scientific language because of its very limited vocabulary capacity. The word 'refrigerator', for example, is mistranslated into Arabic as 'ice maker'. The villagers use 'refrigerator' to simultaneously refer to a refrigerator itself, a flask (hot/cool) and an ice box/cooler. Surprisingly, they never confuse meanings. For them, 'refrigerator' means more like a storage or keeper.

Looking closely at the list in Table 4.7, it can be seen that the villagers appeared to have developed a view that approximates the caloric theory. They also speak about heat as a substance, as indicated in expressions such as 'close the door, so that heat does not come in' or 'if heat comes inside, it will not go out easily' (Expressions 14 – 16, Table 4.7). Surprisingly, they know about hot air flow and how it always rises (Expression1). Thus, almost every house used to have a *barajeel*, which uses hot air and cold air currents to cool down houses (Elmasry, 2017).

Table 4.7 *Basic thermal energy knowledge found in everyday Arabic language which full of misconceptions*

Everyday Arabic expressions	Misconception*
1. Make a hole in the ceiling to let the hot air out. 2. Only smoke rises = Gossip	Heat rises.
3. The hot water has started to make sounds. = It is boiling. 4. Boiled bubbling = He is very mad.	Bubbles mean boiling.
5. I wait for it on something hotter than coal. = Waiting impatiently 6. He is hotter than coal = He is very impatient.	Boiling point is the maximum temperature a substance can reach.
7. Heat stick = Thermometer 8. Those whose hands are in the water aren't like those whose hands are in the fire = they don't experience the same sensation.	Skin or touch can determine temperature.
9. The boiling water starts to smoke = Steam/vapor	Steam is more than 100°C.
10. I wear a jacket to warm me up. 11. Cover the pot with a jute to keep the food hot. 12. Put jute under your clothes to keep you warm. 13. Wrap ice on jute to prevent melting.	Materials like wool have the ability to warm things up.
14. Heat killed us = the weather is hot. 15. If heat comes inside, it will not go out easily. 16. Close the door so that heat does not come in.	Heat is a substance.
17. We are dying from the heat intensity = So hot	Temperature is the 'intensity' of heat.
18. The child's heat is very high; lower it.	Heat and temperature are the same thing.
19. Colder than ice = He is very disconnected.	There is no limit on the lowest temperature.
20. Something that is hot for me is cold for you = you do not give attention to the matter as I gave.	Heating always results in an increase in temperature.
21. Fire does not burn the feet of those which don't step on it = they don't feel what we feel.	Objects of different temperature that are in contact with each other, do not necessarily move toward the same temperature.

**Note. This column taken from Yeo and Zadnik (2001)*

In addition, they developed basic knowledge about thermal equilibrium (Expression 21). They likewise hold some misconceptions about the thermal properties of materials that match their environment, such as those associated with the ability of 'jute' and ‘cloth’ to warm objects (Expressions 10-13). An intriguing possibility is that they developed basic knowledge about insulators, as evidenced by their use of the same material (e.g. jute) to keep different objects either hot or cold (Expressions 10-14). I remember an incident in my childhood wherein a man on a donkey was selling ice logs to the village, where there were no refrigerators. He wrapped the ice logs in jute, and so did we once we have bought them from him. The villagers also believe that the temperature of ice is the lowest temperature that an object can reach, as indicated in expressions such as ‘colder than ice’. Misconceptions such as ‘bubbles mean boiling’ also developed, as indicated in the expression ‘boiled bubbling’ (Expressions 3 and 4). They may also believe that the ‘boiling point is the maximum temperature a substance can reach’ (seeYeo & Zadnik, 2001, p. 498), as indicated in expressions such as ‘he is hotter than coal’ (Expression 6).

Out of 35 common thermal misconceptions listed in the Yeo and Zadnik (2001) work, only 12 basic misconceptions are found in these villagers’ everyday language. This issue, of course, needs further research that is based on structured interviews. The students more likely switch between what they learn using Modern Standard Arabic at school, where their mistakes are regarded as reflecting lack of knowledge, and what they believe and practice through their everyday language, which may be considered misconceptions because they may not align with modern scientific views.

In sum, conceptual change can be advanced by both old and new schemas, but most of the time, old schemas are supported by a high level of satisfaction. Thus, the chances that old schemas will prevail over this competition is always higher. A review of examples of the everyday language used by the participants suggested that they have built minimal knowledge of thermal concepts and that because of the more frequent use of vernaculars over Modern Standard Arabic, the development of the students' understanding is impeded by the influence of their vernacular language and the limitations of Modern Standard Arabic. Rather than receiving scientific information straightaway from an instructor that delivers lessons using Modern Standard Arabic, the students must constantly act as interpreters and translators of the concepts provided through the Modern Standard Arabic language to their vernacular. The speed of interpretation and the availability of vernacular vocabulary for this purpose may be the factors that affect the students' understanding and increase opportunities for old schemas to dominate learning (Donitsa-Schmidt, Inbar, & Shohamy, 2004). On the other hand, some researchers suggested using students' vernaculars language in teaching science to avoid such complications (Donitsa-Schmidt et al., 2004; Karim, 2016; Palmer, 2007).

The next section features re-discussion of Chi's (2013) mental models to unravel how vernacular language plays a role in students' conceptual change process.

4.8.3 Conceptual Change Processed by Vernacular Language

As discussed in Sections 4.7.1, 4.8.1 and 4.8.2, students use three languages in science classes, namely, scientific language, Modern Standard Arabic and vernacular Arabic, thus compelling them to act as interpreters to understand scientific information. Modern Standard Arabic is the medium used to deliver scientific information from a source (teacher, textbook or multimedia) given that it exhibits a greater capacity to accommodate scientific vocabulary over the vernacular, which has less vocabulary capacity.

Table 4.8 illustrates the two-way interpretation that students implement as a means of understanding and showing such understanding. Scientific information from a source is interpreted using a medium (i.e. Modern Standard Arabic), after which the information is interpreted using students' vernacular language. For students to show their understanding, they then have to implement the process in reverse, with information that they know being translated into Modern Standard Arabic from the vernacular language and then interpreted in a way that accords with the scientific view promoted in Modern Standard Arabic (Scenario 1). This can be a very complicated process if it include a teacher, who has to go through all these steps as well to deliver and receive information to and from students.

Table 4.8 *Two-way interpretation process*

Scientific Information↔Modern Standard Arabic↔Vernacular Arabic	Scenario 1
Scientific Information↔Vernacular Arabic	Scenario 2

Sometimes, this interpretation process proceeds very quickly, but most of the time, it goes very slowly, thereby compelling students to hasten interpretation. In this circumstance, students use their vernacular language to understand scientific information straightaway without going through the use of Modern Standard Arabic (Scenario 2), which results in damage to scientific information. According to Chi (2013), damaged information comes in different forms: inaccurate and incommensurate information and damaged information due to missing information, incomplete information, category mistakes or missing schemas. The difficulty of interpretation increases with rising level of difficulty of a concept. For instance, concepts related to processes are more difficult to understand than concepts related to entities (Chi, 2013). Examples of processes are 'heat capacity', 'caloric', 'kinetic energy', 'thermal equilibrium', 'absolute zero', 'specific heat' and 'entropy', and examples of entities are 'molecules', 'conductor' and 'insulator'.

In brief, Saudi students implement two-way interpretation in science classes because of the need to process three languages every time they come across a science concept (Scenario 1). For the most part, however, students take a short cut in interpreting science material by referring directly to their vernaculars without using a medium (Scenario 2). The next section describes how vernacular language is used under a non-existing mental model.

4.8.4 Vernaculars: Interpreting with No Prior Knowledge

In science classes, students sometimes have little to no prior knowledge of to-be-learned concepts, which is necessary for interpretation using their vernaculars. For instance, male students who study at a level as early as Year 4 about the menstrual cycle may have no idea what this concept means or what is related to for cultural reasons; culture prohibits openly discussing women's issues in male environments (Aldahmash & Alshaya, 2012). In this case, students instantly initiate a mental model to keep the interpretation process going between the vernacular and the source of information (missing schemas). For Saudi students, a prior mental model, whether erroneous or correct, is important in accelerating interpretation across the three languages. Without prior knowledge, the interpretation process definitely slows down, thereby affecting students' understanding and achievement. It can also result in disconnection, compelling students to enter an illusory mode of comprehension during class. My experience of teaching physics for almost two decades to these students revealed that the most difficult task is preventing the majority of students from espousing this illusory mode. In computer programming language, information that has not been loaded previously, has no match or is expected is regarded as an error. The same situation may be what confronts these young interpreters when they encounter concepts of which they have no prior knowledge.

Sanbonmatsu, Kardes, and Herr (1992) stated that learning with no prior knowledge prevents individuals from recognising the absence of information that is potentially essential for them to formulate final thoughts about a certain phenomenon. The researchers indicated that the failure to recognise missing information more strongly motivates individuals who do not realise the inadequacy of their knowledge to form extreme judgments than individuals who recognise the incompleteness of their knowledge. They also suggested that individuals with no prior knowledge tend to be more confident about their judgments than those with prior knowledge—a tendency that may affect persuasion, judgment and decision making (Sanbonmatsu et al., 1992). Sanbonmatsu and his colleagues reported unexpected failure in prompting low-knowledge participants to modify their extreme judgments or their confidence in their judgments. The authors found that one-sided persuasive communication more effectively changed the attitudes of individuals with non-existing mental models.

The role of prior knowledge in students' understanding of chemistry has been examined in as early as 1987 by Chandran, Treagust, and Tobin (1987), who found a strong relationship between student achievement and prior knowledge; that is, students with high prior knowledge are more likely to obtain high scores. For conceptual change to occur, conflict between modern science conceptions and old schemas must take place (Chi, 2008) through a stimulation of satisfaction with a new concept and dissatisfaction with an old one (Duit et al., 2008). Chi (2008) argued that individuals with missing prior knowledge are unlikely to undergo changes in their conceptual understanding because such changes occur only when a conflict exists between prior knowledge and scientific knowledge. Both Hewson and Hamlyn (1984) and Vosniadou (2008) suggested, however, that individuals with no prior knowledge are at a relative advantage in learning correct scientific ideas about any concept compared with Westerners because they do not have to set aside the misconceptions stemming from outdated scientific notions of caloric heat. Contrastingly, Chi (2008) pointed out that individuals with no prior knowledge have no clear conceptualisation and are easily misled by perceptual similarities that prompt individuals to ascribe causal explanations to different phenomena.

To sum up, prior knowledge is essential to motivate students, and one-sided persuasive communication can keep the learning process going. Conversely, the absence of prior knowledge may slow down the interpretation process for students who study using one language, speak another and use materials that are written in yet another language. These aspects can lead to disconnection and drive students to enter an illusory mode of comprehension.

4.9 Summary

This chapter described the conceptual change approach and its association with cognitive conflict. The chapter also discussed how students learn science. Students' misconceptions have been reviewed in light of Chi's (2013) mental models. Those misconceptions created by students due to their mental model prevent students from understanding science concepts and hinders conceptual change from occurring. According to Posner et al. (1982), conceptual change necessitates two conditions: dissatisfaction with an old concept and high satisfaction with new concepts owing to their intelligibility, plausibility, and fruitfulness. Duit et al. (2008) suggested three scenarios that can arise from the competition between satisfaction and dissatisfaction with new and old concepts: (a) If a new concept fails to trigger optimal dissatisfaction with an old one, then it may be assimilated alongside the old concept; (b) if both the old and new concepts trigger an equal level of dissatisfaction/satisfaction, then two conceptual events can happen; and (c) if the new concept triggers a high satisfaction, conceptual change can occur. The cleverness evident in Arabian knowledge was highlighted with some examples of conceptual change driven by Arabian narratives. Several examples from the Saudi environment were interpreted using satisfaction. The role of spoken Arabic vernaculars in conceptual change and in students' misconceptions was also discussed. Finally, the chapter described how students may engage in interpretation using their vernaculars with and without prior knowledge.

CHAPTER 5
METHODOLOGY

5.1 Introduction

This chapter discusses the methodology used to obtain answers to Research Questions 1–4 (presented in detail in Chapters 6 and 7), which are related to misconceptions of thermal energy amongst Saudi female students and their teachers as well as the possible sources of these misconceptions. Two sources were used to collect data on the issues for Research Questions 1–3. The first is the one-tier multiple-choice TCE that measures *students'* conceptual understanding and misconceptions (i.e. responses to Research Questions 1 and 2), and the second is the Science Teachers' Professional Development Workshop questionnaire, which was designed to measure *teachers'* level of understanding of thermal concepts (i.e. responses to Research Question 3). Both sources of data were statistically examined through quantitative analysis (i.e. t-test, reliability test, and triangulation) and qualitative analysis (i.e. descriptions of the characteristics of the sample and study context). The final results served as a reflection of conceptual change in the Saudi teachers and students. Research Question 4 was illuminated via examinations of two sources of data, namely, textbook content and language/terminology. The four research questions pursued in this research are as follows:

1. What thermal concepts are understood scientifically by Saudi female high school students before and after instruction?

2. What misconceptions are formed by Saudi female high school students about thermal energy before and after thermal energy instruction?

3. What is the level of thermal conceptual understanding exhibited by Saudi female high school teachers?

4. What are the possible sources of Saudi female high school students' misconceptions regarding thermal physics?

The rest of the chapter is structured in three main sections: research design, data collection, and data analyses. Section 5.2 presents the research design used in this study, and Section 5.3 describes the three data source collection strategies. Section 5.4 presents the first source of data as responses to Research Questions 1 and 2 using the TCE instrument; Section 5.5 presents the second source of research data as a responses to Research Question 3 based on the findings from the workshop; and Section 5.6 presents the research data as the responses to Research Question 4 and explains the methods used to review textbook content and language/terminology issues. Section 5.7 states the procedure used to analyse the data as well as comprehensively describes the triangulation strategy used to support the findings.

5.2 Research Design

To maximize the information collected from this study and to minimise the weakness of one method data collections (Creswell & Clark, 2017), a mixed methods research design was developed and used to cover all research questions of this study. The purpose of the mixed methods design defined by Johnson et al. (2007), as to acquire different but integrated information to explain the same phenomena that the research deals with and to provide the best understanding of the research problem. Figure 5.1 illustrate the research design which used if this study.

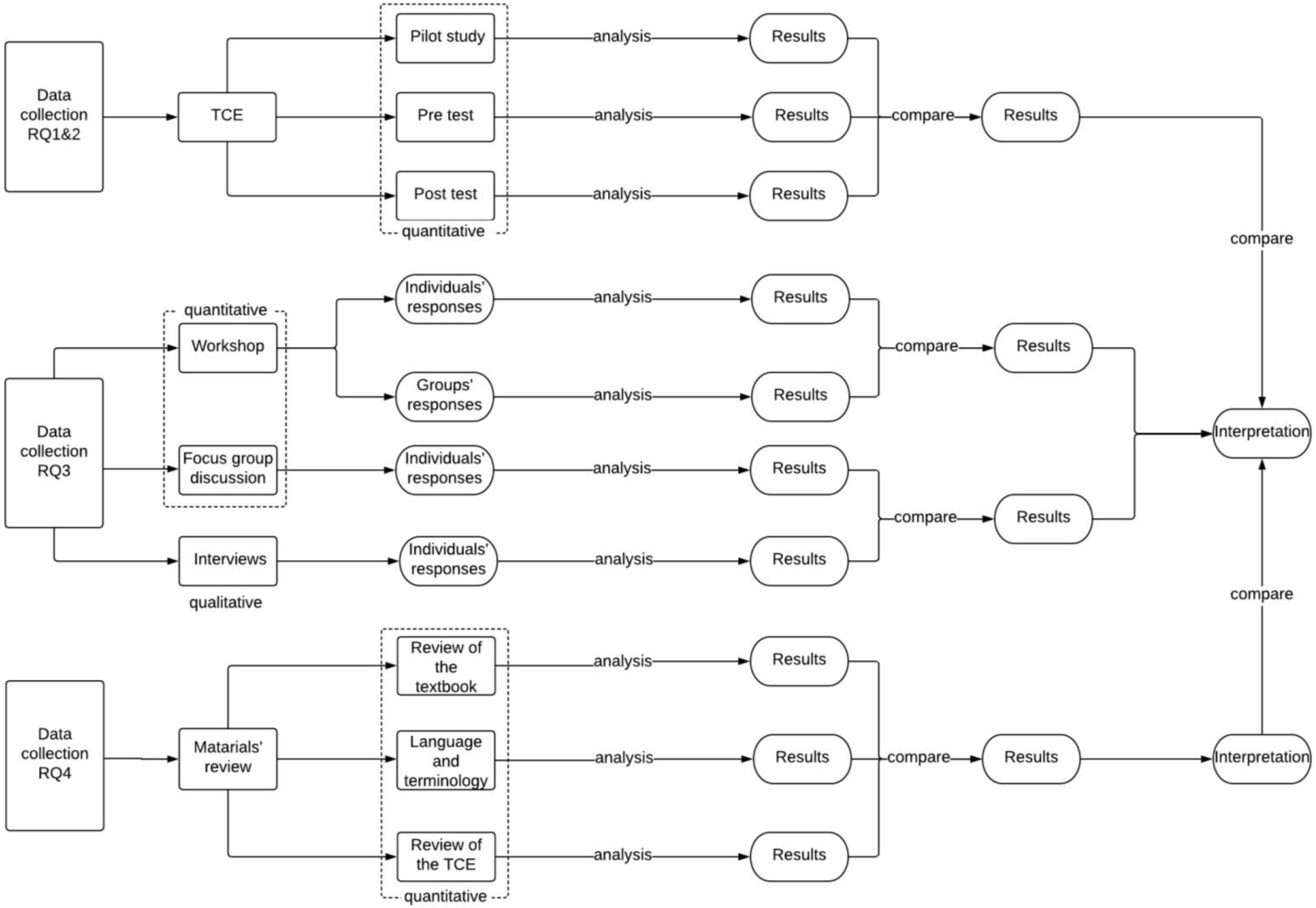


Figure 5.1 Research design

5.3 Data Collection

Research data collection is the information gathered from different sources to address the research questions were intended to monitor how the Saudi female students and their teachers respond to conceptual change activities during pre- and post-testing using the research means. The data collected to respond to the four research questions are covered in this chapter. In order to monitor how the Saudi female students and teachers conceptually understand thermal concepts, two sources of data were collected from: the TCE developed by Yeo and Zadnik (2001) and the Science Teachers' Professional Development Workshop. The TCE by Yeo and Zadnik (2001) was directed towards four main categories for assessment, namely, students' misconceptions of heat, temperature, temperature change and heat transfer and thermal properties of materials.

The Thermal Concepts Evaluation was used as the main diagnostic test of *students'* thermal misconceptions as an instrument for illuminating Research Questions 1 and 2. The Science Teachers' Professional Development Workshop which involved workshop training sessions, a focus group discussion and interviews (see Appendix A), was employed as an additional diagnostic mean for examining *teachers'* thermal misconceptions as a pathway to addressing Research Question 3.

The Workshop was designed in a way that enabled teachers to think about the thermal concepts that they have not previously considered with the intention of helping overcome any identified misconceptions by engaging in conceptual change. The Workshop was also developed along lines that prevent direct exposure to the TCE items, that is, by concentrating on thermal concepts. After the Workshop was completed, the teachers were assessed and provided with all the information necessary for them to advance their students' understanding and correct any misconceptions arising from the learners. Then, both the teachers and students were introduced to the TCE. This procedure was implemented for three reasons: to examine whether the Workshop was able to motivate the teachers to challenge their beliefs (conceptual change), to determine whether they are ready to apply what they learned to a new situation and to ascertain whether they are able to deliver new knowledge to others (i.e. their students). Thus, although the TCE was identified as the first research source of dada in this work, its use came second during the data collection process. Its labelling as 'first' was intended to signify that the test was the main driver of the Workshop given that the activities involved in the latter were designed on the basis of the TCE and all its aspects. Correspondingly, the design of the Workshop was structured around five categories: heat transfer and temperature change, the difference between heat and temperature, boiling, freezing and melting and heat conductivity and equilibrium that encompass the four categories of items in the TCE. The TCE yielded two sets of data, namely, the students' responses to the pilot study and their responses to the pre- and post-tests. Figure 5.2 shows the Workshop yielded four sets of data sources, namely, the teachers' answers as individuals, their responses as groups, their responses in the focus group discussion and their answers in the interviews.

Workshop → TCE pre → Teaching → TCE post → Group discussion → Interview

Figure 5.2 The sequence of the methodological design of the two sources of data is depicted thus.

To sum up, the research methodology was designed to illuminate the issues highlighted in Research Questions 1 to 4. For this purpose, the TCE and the Science Teachers' Professional Development Workshop were administered to the participants. To monitor how the Saudi students and teachers respond to conceptual change, their responses in the two sources of data were measured on multiple occasions. Such measurement was enabled by the thermal concepts training of the teachers without exposure to the TCE items and their subsequent teaching of thermal concepts to their students. After this, the manner by which the students responded to conceptual change was determined by measuring their performance in the TCE post-test. The two sources of data are covered in more detail in the next sections, which delineate the preparation of the means and the participants' demographic characteristics and other attributes.

5.4 The First Source of Data

5.4.1 Thermal Concept Evaluation (TCE)

The TCE was directed towards identifying the students' misconceptions of thermal physics as a means of illuminating Research Question 1: 'What thermal concepts are understood scientifically by Saudi female high school students before and after instruction?' and Research Question 2 'What misconceptions are formed by Saudi female high school students about thermal energy before and after thermal energy instruction?' What follows is a detailed account of the test preparation and participants' demography.

5.4.2 Test Preparation

Chang, Chau and Holroyd (1999) stated that in assessing a group of participants who are non-English speakers, translating a previously developed instrument is the best option (as cited in Maison, 2013). For the current study, the TCE developed by Yeo and Zadnik (2001) was chosen as the diagnostic test of Saudi female high school students' misconceptions regarding thermal concepts in physics. The test was selected because of its wide usage as a tool for diagnosing thermal misconceptions confirmed its effectiveness in identifying students' misconceptions on the basis of their everyday language. The ethics' approval was obtained from Curtin University, Office of Research and Development (see Appendix B). Thermal Concepts Evaluation consists of 26 multiple-choice items, eight of which have a multiple choice numerical answer options (Q1–Q7 and Q17) and the rest require statement answers (see Table 5.1 and Appendix C). The maximum possible score is 26 points, where each question donate one point. The consent and information forms have been approved too (see Appendix D)

Table 5.1 *Examples of TCE items and misconceptions associated with each answer*

TCE question	TCE question's options	Misconceptions
1. What is the most likely temperature of ice cubes stored in a refrigerator's freezer compartment?	a. –10°C b. 0°C c. 5°C d. It depends on the size of the ice cubes.	-Ice is at 0°C and/or cannot change temperature. -The temperature of an object depends on its size.
4. On the stove is a kettle full of water. The water has started to boil rapidly. The most likely temperature of the water is about:	a. 88°C b. 98°C c. 110°C d. None of the above answers could be right.	-Heating always results in an increase in temperature. -The boiling point of water is 100°C (only).
12. Mel is boiling water in a saucepan on the stovetop. What do you think is in the bubbles that form in the boiling water? Mostly:	a. Air b. Oxygen and hydrogen gas c. Water vapor d. There's nothing in the bubbles.	-The bubbles in boiling water contain "air," "oxygen," or "nothing."

The test has been translated and examined multiple times in different languages, including German, Bosnian, Mexican, Korean and Arabic. It is of a one-tier design, thus offering both students and teachers a reasonable time frame within which to answer the test items. The current translated version of the TCE was compared with the version of two Arabian researchers (Moroccan and Jordanian), with permission obtained from the scholars through personal communication. The TCE translated for the present study was then sent to two Saudi colleagues at the Department of Science and Engineering of Curtin University's School of Physics to verify the translation. All the comments in the verification were incorporated into the final translated version. To ensure the face validity of the final Arabic version, 'back translation' (i.e. interpreting a document translated into another language, translating it back to the original language and comparing the two), was conducted by an independent bilingual translator, after which this version was again validated through a pilot study. For the pilot study, two copies were made available: a physical hard copy for the group tests and a computer version for the individual tests administered via school computer facilities. For the main research, bubble-style answer sheets were prepared using GradeCam® version 3 beta software (Kılıçkaya, 2017). Each answer sheet was customised to display a student's ID as a unique code number, the name of the student's school and her Year level; these fields were filled in automatically so the students had no need to do so themselves. The TCE answer sheet also contains fields for demographic information (see Appendix C).

As stated earlier, Since Yeo and Zadnik (2001) presented thermal concepts evaluation, it has been used as a reliable standard for measuring the most common misconceptions among school students. Figure 5.3 illustrates the application of the countries since has been 2001.

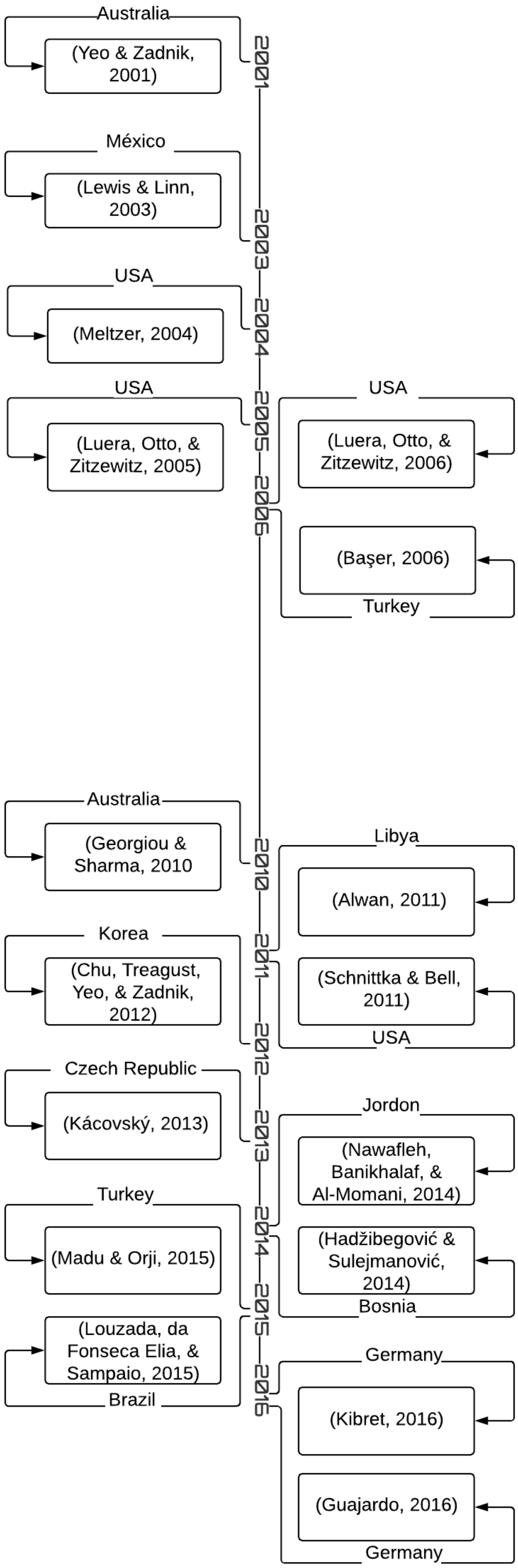


Figure 5.3 Some of the Studies That Used the TCE in Full or Part

5.4.3 The Pilot Study

The pilot study was conducted for a number of reasons: to determine student familiarity with the test content, measure the time required to complete the test, reduce and identify of any potential problems with the translation or any ambiguous language and detect early on any fallacies held by this sample of Saudi female high school students. All the respondents exhibited knowledge of the test content, and the test took around 30–45 minutes to complete. The pilot study results revealed the existence of several thermal misconceptions based on the students' everyday language.

5.4.4 The Main Study

The study's respondents were recruited from public schools in the Eastern Province of Saudi Arabia. Selecting this province as the context for investigation presented several advantages. First, the researcher is a native of the province and is therefore familiar with the location. Second, the Eastern Province is the third largest in the country and is home to numerous high schools (Central Department of Statistics & Information, 2013; edueast.gov.sa), thus providing the researcher with a variety of testing site options. Third, the credits-based system does not cover the entire Kingdom and has been applied only in Saudi Arabia's largest provinces, including the Eastern Province (Salman, 2011). For this reason, collecting data from this province was significantly easier and more beneficial than it would have been had the other provinces been chosen as study sites.

A sample of 742 Year 11 female high schools students completed the pre- and post-tests. Thirty female science teachers recruited from 28 schools participated in the Workshop. The distribution of the teachers covered approximately 20,000 square kilometres of the Western Province of Saudi Arabia, starting from El_Khafji on the boundary of Kuwait to Hafar Al Batin on the boundary of Iraq down to Dammam City near Bahrain. The teachers' careers spanned a maximum of 25 years and a minimum of one year. All the participants were informed of the mission and purpose of the study, after which their questions about privacy and other concerns were addressed prior to the test. Permission from all the participants was obtained.

All the schools participating in the study have government-supplied buildings as their campuses. Class facilities were observed to determine whether the classrooms have learning and teaching aids that can enhance students' levels of understanding. The laboratories of all the participating schools were also inspected. All the laboratory technicians hold a Diploma in Laboratory Management and are in charge of preparing experiments for physics teachers, monitoring the laboratory inventory and completing documentation about inventory and laboratory use by teachers. The laboratory technicians were asked a few questions about laboratory facilities and the availability of thermal energy equipment, which were also inspected and photographed.

Certain schools, particularly large ones, normally have learning resource rooms equipped with one or more computers, a smart board and a projector. All the participant schools have this room, but only one had sufficient facilities, such as a smart board, a projector, a laptop and a document camera, in each of its 16 classrooms. Because students are easily bored with in-class or laboratory lessons, teachers conduct classes in learning resource rooms, but none of the physics teachers use the smart board as a tool for lesson delivery. Of the items in the school with sufficient facilities, only the projector is used every day; none of the smart boards and document cameras have been turned on even once. The interviewed teachers stated that they do not use either the smart boards or document cameras because they do not know how to incorporate usage into a 45-minute class period. In addition, efforts at familiarisation themselves with the technology would consume a large proportion of class time [time limitation] (Teacher # 3, personal communication, 2014). The teachers therefore prefer to use computers and projectors because these are easy to operate. The variety of facilities in the schools should encourage the teachers to use such equipment as a means of improving the learning environment and eliminating boredom, but technology has proven to be one of the difficulties that they face in classroom instruction.

5.5 The Second Source of Data

5.5.1 Teachers' Workshop

The Workshop served two main purposes. It was a sources of data for addressing Research Question 3 which revolves around the Saudi female physics teachers' level of understanding of thermal energy concepts, and a means of monitoring how the teachers responded to conceptual change. The Workshop was designed to be over a three-day period of time. The preparation of the Workshop started with the identification of the most common misconceptions regarding thermal concepts, guided by a list of some common thermal misconceptions (Yeo & Zadnik, 2001). For the documentation of the teachers' group answers during the Workshop (see Appendix E and Table 5.2), activity booklets that were previously checked and reviewed by a team of professors at Curtin University were prepared.

Table 5.2 *Examples of the Workshop questions' containing the same information as that in the TCE but featuring different situations*

Misconceptions	TCE questions	Workshop questions' attempts* to learn the new schemas			
		1st attempt	2nd attempt	3rd attempt	4th attempt
The bubbles in boiling water contain 'air', 'oxygen' or 'nothing'.	What do you think is in the bubbles that form in boiling water?	1.How can you explain the situation wherein water is boiled, the bonds between water molecules breaks (H_2O & H_2O), whereas the bonds inside the molecule itself do not (i.e. oxygen & hydrogen)?	2.Is water vapour a liquid or gas?	3.What components are found in bubbles as water boils?	
When temperature at boiling remains constant, something is 'wrong'.	[water likely boiling] Five minutes later, the water in the kettle is still boiling. The most likely temperature of the water now is?	4.If boiling water is placed on top of a stove and we turn the heat up to the highest setting, what will happen to the water temperature? (Harrison et al., 1999)			
The boiling point of water is 100°C (only).	On the stove is a kettle full of water. The water has started to boil rapidly. The most likely temperature of the water is?	5.Water boils at 100°C. Does it boil at 50°C?	6.Did you hear about the 'ice bucket challenge'? There is another one called 'boiling water bucket challenge'. Can you put your hand in a boiling water bucket and win the challenge?	7.What is in the space above a boiling kettle's spout?	8. [Experiment: Boiling in a syringe] 9.We did not heat the water to make it boil inside the syringe. Where did the water get

Misconceptions	TCE questions	Workshop questions' attempts* to learn the new schemas			
		1st attempt	2nd attempt	3rd attempt	4th attempt
					the heat from?(FlinnScientific, 2012)
Materials like wool have the ability to warm things up.	Why do we wear sweaters in cold weather?	10.What will happen to a thermometer if we cover it with heavy wool cloth?			
Heating always results in an increase in temperature.	Five minutes later, the water in the kettle is still boiling. The most likely temperature of the water now is?	11.If boiling water is placed on top of a stove and we turn the heat up to the highest setting, what will happen to the water temperature?	12.True or false: Adding more heat causes a rise in an object's temperature.		
Water cannot be found at 0°C.	[When ice cubes stated to melt] what is the most likely temperature of water at this stage?	13.What is the state of the water at zero degrees?	14.Which one do you prefer to cool down a jug of juice: a cup of water at zero degrees or a cup of ice at zero degrees?	15.Can matter be found in two statuses at the same time and place?	16.[Mixture of water and ice] What is the temperature of water and ice in this case?
The temperature of an object depends on its size.	What are the most likely temperatures of a plastic bottle and the cola it holds? [both inside the fridge]	17.Which object has a higher temperature: a big cube of ice or a small cube of ice?			
A cold body contains no heat.	Pam asks one group of friends: 'If I put	18.When two cups are placed in a freezer, which	19.Which object has more heat: a teapot or an iceberg	20.Which object has a higher	21.Which object has more heat: a

Misconceptions	TCE questions	Workshop questions' attempts* to learn the new schemas			
		1st attempt	2nd attempt	3rd attempt	4th attempt
	100 grams of ice at 0°C and 100 grams of water at 0°C into a freezer, which one will eventually lose the greatest amount of heat'?	will lose more heat: a cup of water at zero degrees or a cup of ice at zero degrees?	(Yesican-science.ca, 2016)?	temperature: a big cube of ice or a small cube of ice?	cup of water or a tub of water at room temperature?
					22.5th: Which object has more heat: a cup of ice or a gigantic iceberg?
Ice is at 0°C and/or cannot change temperature.	What is the most likely temperature of ice cubes stored in a refrigerator's freezer compartment?	23.The temperature reading inside the freezer section was -18°C. What does that mean?	24. What is the most likely temperature inside a fridge and inside the freezer section?	25.[Video] At 5:55, he said the water temperature was –4°C of the mixture (water + ice), how could be that?(Periodic Videos, 2013)	

**Note: These attempts have been further explained in details in Chapter 6 Section 6.5.*

The activity booklets were matched with a PowerPoint presentation. Each booklet consists of 41 activities designed to enhance the teachers' understanding of thermal concepts. Next to each activity is a short sample that guides teachers on how to respond to each question and post their answers (i.e. as a group or as individuals). At the end of the booklet is a short Likert-style survey about the Workshop. A blank space for extra comments is also provided. A 37-page physics teacher handbook that contains a guide for understanding thermal concepts and a list of the most common thermal misconceptions of students was also created. The handbook was distributed to the attendees at the end of the Workshop.

To ensure that the teachers were able apply the new concepts in new situations and ensure conceptual change, the Workshop was designed to enable the monitoring of conceptual change for each thermal concept reviewed in the Workshop. Specifically, monitoring was carried out through multiple postings of information regarding a certain thermal concept in different situations and through the use of different tools (i.e. experiments, plotting graphs, true and false questions, open –ended question, puzzles, reading Figures and pictures, reflecting in photos and YouTube videos), without exposing the teachers directly to the items in the TCE. The Workshop consist of several steps and implemented as follows: the researcher first provided a PowerPoint presentation regarding the activities, after which the teachers were given the chance to think together as a group about a given question and its possible answer. Each group was then asked to write the answers on a small white board provided by the researcher, and each group member was instructed to post her individual response on the Poll Everywhere platform using her mobile phones (see Figure 5.4).

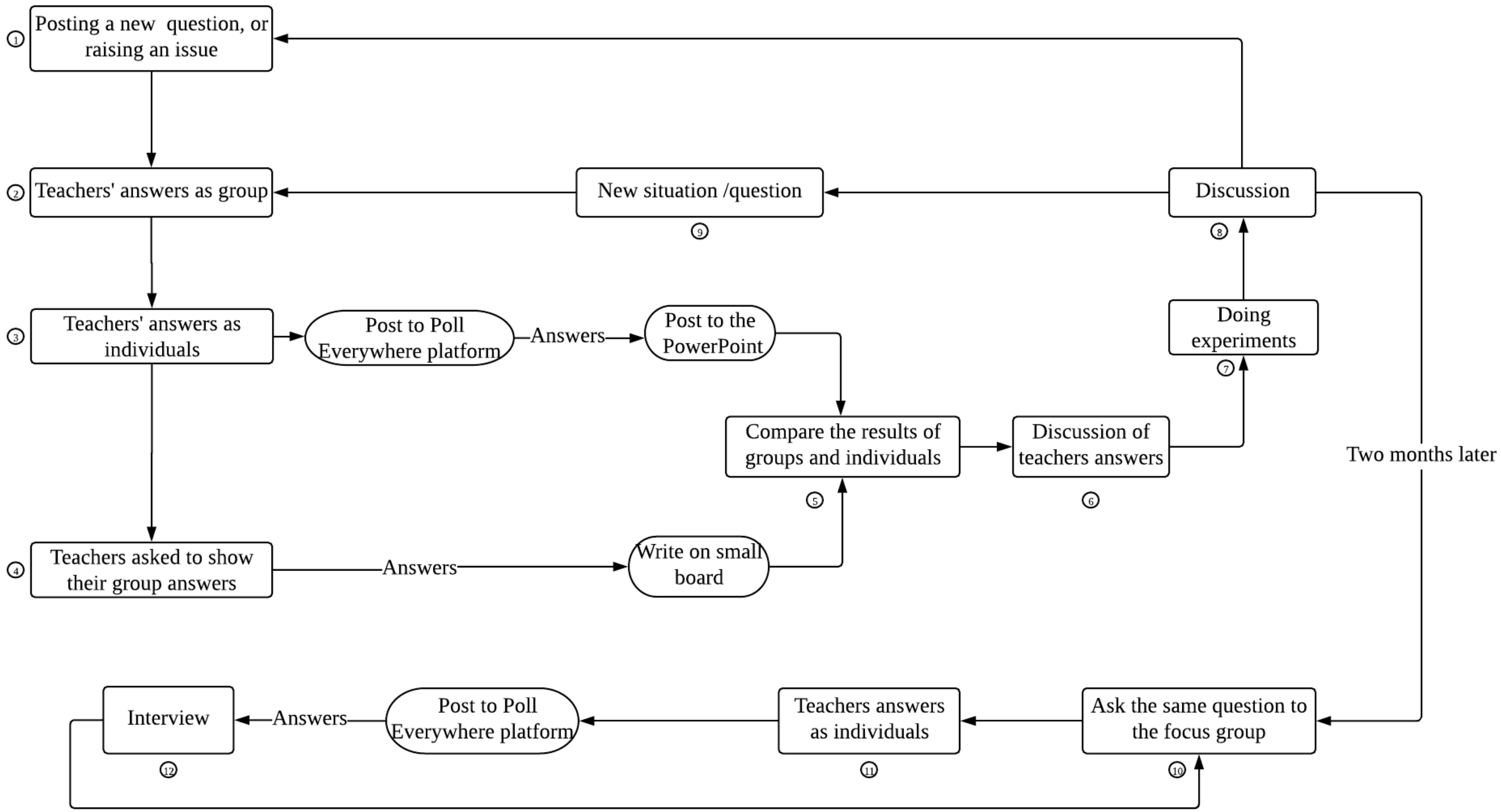


Figure 5.4 Workshop design

Subsequently, the groups were asked to show the answers that they noted on the small white board earlier, and the researcher wrote the groups' responses on the class white board without referring to group names. Some of groups' answers were also photographed. The researcher presented a live slide that showed the individual answers posted on Poll Everywhere, then discussed the individual answers in conjunction with the group responses. When applicable, the teachers were instructed to carry out an experiment using some advanced devices provided by the researcher. What followed was the discussion of the experimental results and an explanation of why their answers were correct or incorrect. Next, the researcher applied the results in a new example or situation. Some of the concepts were discussed and measured up to five times during the Workshop sessions, and others were elevated in a way that imposed a new level of challenge and inspired a new level of thinking (i.e. Q16 and Q45). Finally, every activity and question in the Workshop served a specific purpose (see Table 5.3). Moreover, Figure 5.5 shows the Workshop's timeline.

Table 5.3 *The Workshop aims*

AIM	QUESTION
1.To determine whether the teachers use their senses to explain what they observe	What is the temperature of the boy and the background according to the image provided below?
2.To determine whether the teachers provide intelligible answers to questions.	What is the temperature of the water in the cup? [mixture of water and ice] (Wheeler & Mazur, 2000)
3.To determine what the teachers' beliefs are regarding whether the boiling point of water depends on the amount of water or the amount of heat?	Draw a graph of the boiling point of each of the three cases below, with the plot starting from room temperature to the boiling point. Will the graph differ from one case to another?
4.To determine whether teachers differentiate between heat and temperature	Which object has more heat: A (boiling pot of water) or B (gigantic iceberg)? (Yesican-science.ca, 2016)
5.To determine whether the teachers know that water can be found in liquid form at 0°C	What is the state of water at 0°C?
6.To determine whether the teachers are aware of the components of boiling water bubbles	What components are found in bubbles as water boils?
7.To determine whether the teachers know that water can boil at less than 100°C	Water boils at 100°C. Is it possible for it to boil at 50°C?
8.To determine whether the teachers believe that covering a thermometer with heavy cloth can change its temperature readings	What happens to a thermometer reading if you cover the thermometer with heavy cloth?
9.To determine whether the teachers know the temperature inside a freezer	What is the temperature inside a freezer?
10.To determine whether the teachers know the temperature of objects, such as a doll	What is a doll's temperature?

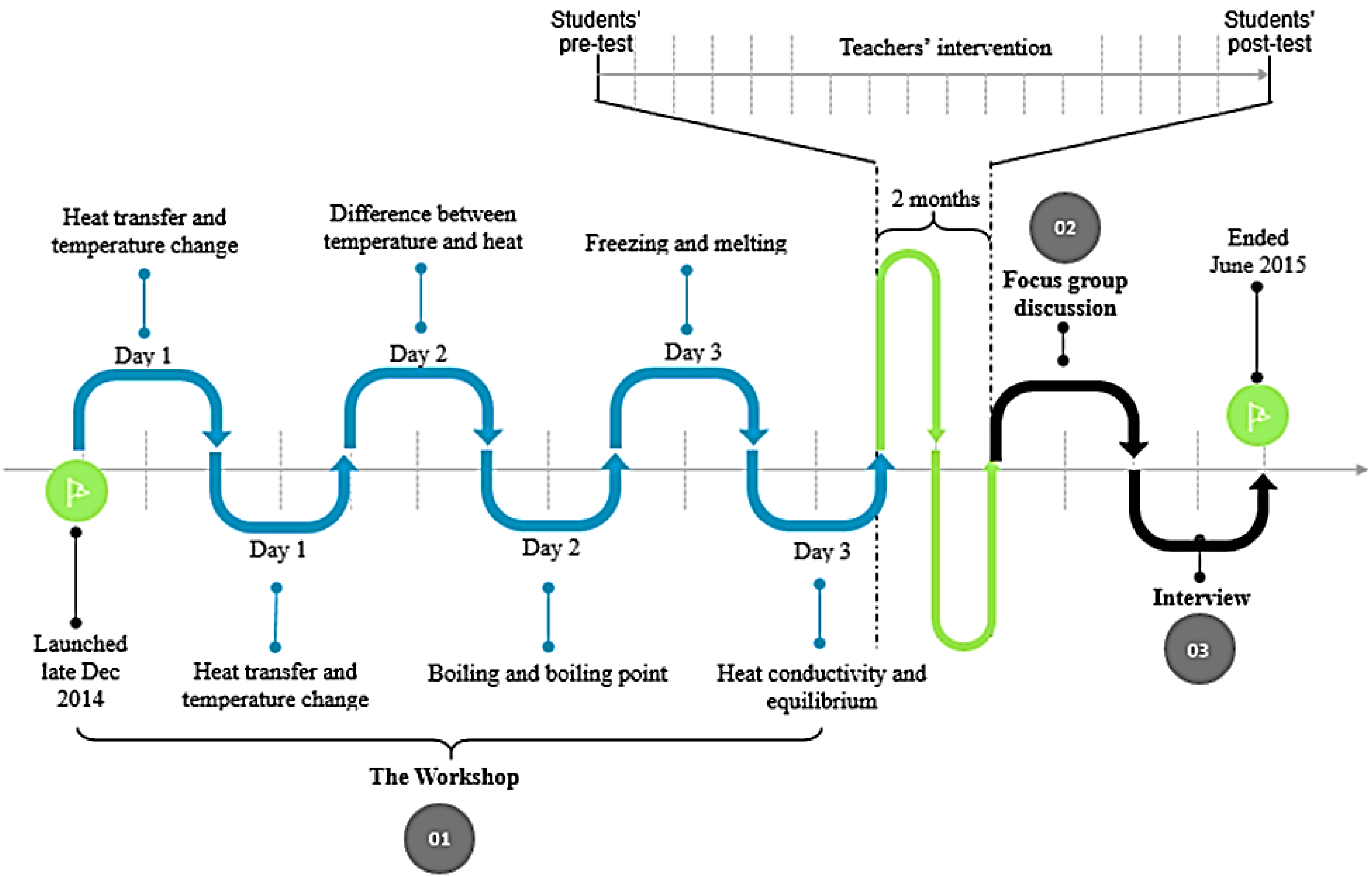


Figure 5.5 The Workshop's timeline

5.5.2 Teachers' Focus Group Discussion

The main purpose of the focus group discussion was to monitor the occurrence of conceptual change in the teachers through the repetition of the thermal concepts discussed during the Workshop sessions, the measurement of the teachers' answers and the comparison of their focus group responses with their Workshop responses. Forty-nine teachers participated in the focus group discussion. The discussion was conducted primarily to deliberate on the Workshop activities and emphasise the issues highlighted in them, but it was also used as an opportunity to answer the teachers' questions, share ideas with them and support them. The focus group discussion was carried out over the WhatsApp interface (v. 2.11.16), on which thermal concept questions were posted for viewing by the participants. Their responses were sent over the Poll Everywhere platform. The questions were designed to enhance the teachers' understanding of thermal physics concepts and correct misconceptions through different examples in different situations. In cases where any response required clarification, a private message was sent to the teacher needing a clarification to ask for elaboration of the query. These exchanges were saved for investigation of the progress with which the teachers' old concepts changed.

5.5.3 Teachers' Interviews

The teachers' one-to-one semi-structured interviews were parallel with Teachers' focus group discussion sessions. The purpose of the interviews was also to monitor conceptual change in the teachers, this time through the administration of the questions discussed in the Workshop sessions or during the focus group discussion, with slight modifications. The modified questions, accompanied by multiple-choice response answers or fields for open-ended answers, were posted on Poll Everywhere. Basis of their corresponding multiple-choice answers during focus group discussions, some teacher was chosen for participation in one-to-one-semi-structured interview (see Appendix A). When applicable, the teachers' interview responses were matched with their Workshop and focus group answers. Table 5.4 gives an example of alternative conception which listed by Yeo and Zadnik (2001) and how the same information been presented in The Workshop, focus group discussion and the interview.

Table 5.4 *An example of question to measure teachers' conceptual understanding over different stages.*

TCE question	Workshop question	Focus group question	Interview question
Q4.On the stove is a kettle full of water. The water has started to boil rapidly. The most likely temperature of the water is about? (Yeo & Zadnik, 2001, p. 498)	1st: Water boils at 100°C. Does it boil at 50°C? 2nd: Did you hear about the 'ice bucket challenge'? There is another one called 'boiling water bucket challenge'. Can you put your hand in a boiling water bucket and win the challenge? 3rd: What is in the space above a boiling kettle's spout?	Water boils at 100°C. Does it boil at 50°C?	What is the temperature of water vapour in this case? 

In sum, two sources of data were used to examine the level of understanding of Saudi high school students and teachers regarding thermal concepts and to investigate their thermal misconceptions. The TCE and the Science Teachers' Professional Development Workshop were used to measure the Saudi students' and teachers' misconceptions, respectively. The Workshop was designed to prevent the direct exposure of the teachers to the TCE items. They were instead provided with explanations, discussions, experiments, videos and examples. The results of the two sources of data were then employed as bases for exploring how the Saudi teachers and their students respond to conceptual change. The next section explains the methods used to look into the possible sources of misconceptions among the Saudi students and their teachers.

5.6 The Third Source of Data

Two sources of students' misconceptions were speculated as potentially preventing them from undergoing conceptual change—textbook content and language and this is the source to respond to Research Question 4. Textbooks and language have been frequently explored as misconception sources by many researchers (Albadi et al., 2018; Cho, Kahle, & Nordland, 1985). The present study was motivated primarily by limitations in the review of Saudi physics textbooks and language issues and how these factors contribute to the formation of misconceptions, as well as how Saudi students and their teachers will engage in conceptual change.

5.6.1 Textbook Content

The original English version of the Saudi physics textbook published by Zitzewitz (2005) and its translation into Arabic published by Obeikan Library (one of the largest publishers in Saudi Arabia) were reviewed. Considerable attention was paid to the thermal energy topic, which is located in Chapter 12 of the original textbook and Chapter 5 in the Arabic Physics 3 textbook. Chapter 5 was compared line by line against the original to identify any mistranslation, misleading information or ambiguous language that does not correspond with the meanings intended by the source. All the Figures, charts, equations, experiments, examples and exercises were carefully read. The amendments to some of the phrases and examples in the source were determined to find a link between the misconceptions formed by Saudi students and teachers and the frequency at which the phrases appear in the Arabic version. To ensure the accuracy of the translation of the publisher, quoted statements from the Arabic version were subjected to two-way translation, for which the help of bilingual colleagues was sought. The results of the textbook review were triangulated against the findings of the TCE pilot study and the main study which will explained in Chapter 7 Section 7.1.

5.6.2 Language and Terminology

As part of the endeavour to elucidate students' misconceptions sources (Research Question 4), the language and terminology in the textbook (Chapter 6 and 7) and the students' spoken vernaculars (Chapter 4) were reviewed. As mentioned previously, Saudi students use three languages to communicate: Modern Standard Arabic, which is used in schools; vernacular language, which is used in daily life; and the scientific language found in translated textbooks. Modern Standard Arabic serves as the medium of delivering scientific material to students, but its use is limited to educational settings and the media. Vernacular language is used for almost everything else. As asserted earlier in Chapter 4 Section 4.6, conceptual change necessitates that dissatisfaction with old schemas and satisfaction with new concepts be at the highest levels. Given language barriers, however, this condition is unsatisfied most of the time, thereby making students' errors appear as though they are robust misconceptions. Disentangling this issue may help students correct their errors through the conceptual change approaches suggested by researchers. The investigation of language and terminology involved many translations from source materials, considerable reading of old Arabian narratives and securing an understanding of different vernacular languages.

5.6.3 Teachers' Practical Knowledge

Two of the most popular teachers' training programs in Saudi Arabia were reviewed to match their goals with the real teachers' practical knowledge. The first programme is conducted by the Saudi Department of Education, and the one is conducted by the Saudi Oil Company (ARAMCO). The first program has been analysed through the published training material. The second one was analysed through the notes that the researcher has made during attending one of these program sessions. All the material go through two way translation from Arabic to English and back by some volunteer bilingual language academic body. Figure 5.6 illustrates students' sources of misconceptions which investigated in this study and the previous studies that mentioned these sources.

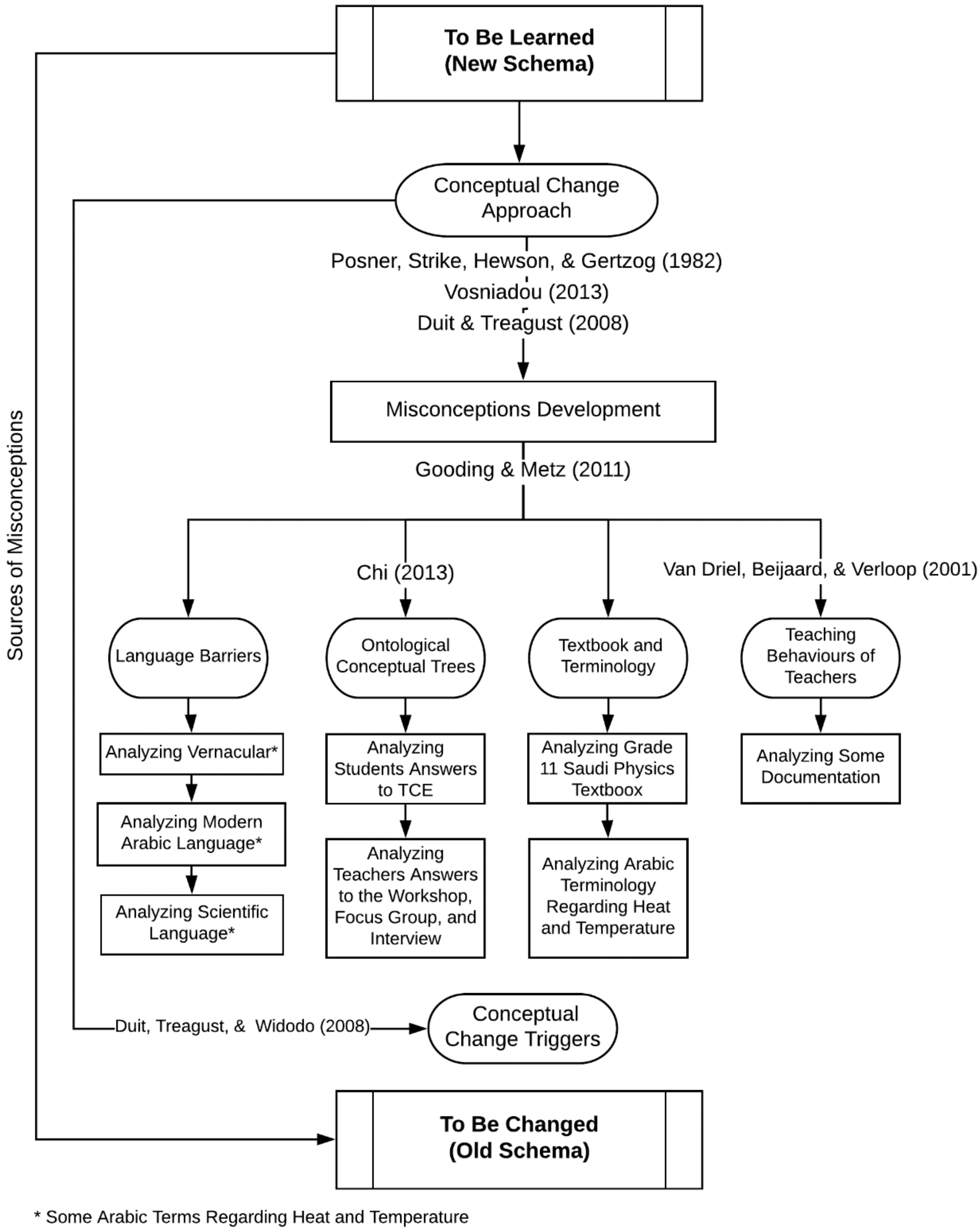


Figure 5.6 Possible students' sources of misconception

5.7 Data Analysis

5.7.1 Data Analysis Procedures

The data collection, encompassing the administration of the TCE and the Workshop and the immediate analysis of responses when needed, was supported by software programs. A variety of data collection tools and instant data analysis software was critical because of the time constraint imposed on the data collection and the limited resources to which the researcher had access.

The first set of software programs, which was employed to administer the means, consisted of Microsoft PowerPoint, which was used to present the Workshop information slides and prepare the teachers' individual answers for posting on the Poll Everywhere website; Google Forms, which was used to create the TCE online forms that the students filled in during the pilot study; the Poll Everywhere platform (Miller, Lasry, Lukoff, Schell, & Mazur, 2014), which was used to collect the teachers' individuals answers in the Workshop sessions; WhatsApp, which was used to collect the teachers' responses in the focus group discussion and interviews; and GradeCam®, which was used to create the students' bubble answer sheets. The second set of software programs, which was adopted to analyse the responses to the two sources of data', comprised SPSS version 23, which was used to obtain most of the information analytics on the students' answers; Microsoft Excel, which was used to organise all the students' information and responses to the pre-test, post-test and pilot study; and Poll Everywhere, which was used to examine the teachers' answers in the training sessions, focus group discussion and interviews. All names and other personal information were assigned codes to ensure anonymity.

5.7.2 Data Triangulation

Data triangulation is 'a process of qualitative cross-validation' (Jick, 1979; Wiersma, 2000) that, if used correctly, can maximise and improve the 'validity of evaluation and research findings' (Mathison, 1988). Triangulation involves comparing and weighing information that has been collected via three qualitative research methods: interviews, surveys and reflective journals or field notes (Oliver-Hoyo & Allen, 2006).

Triangulation yields a variety of 'possible estimates', on which the answer that a given study seeks should be founded (Mark & Shotland, 1987).

To ensure that meaningful insights and sufficient support for the current study's findings were derived, triangulation was performed to link the data obtained from the two sources of data. This linking was very important as it enabled the appropriate association of each misconception to its source which may help students facilitate conceptual understanding. As an ongoing process, triangulation in this study was employed frequently for folding and unfolding misconceptions cases, wherein each source of information was validated against the rest of the data sources. The specific approaches to triangulation used in this work are as follows:

Triangulation to validate the Workshop findings

The teachers' individual and group answers in the Workshop were triangulated against their responses in the focus group discussion and the interviews. The changes in the teachers' answers were monitored at each stage.

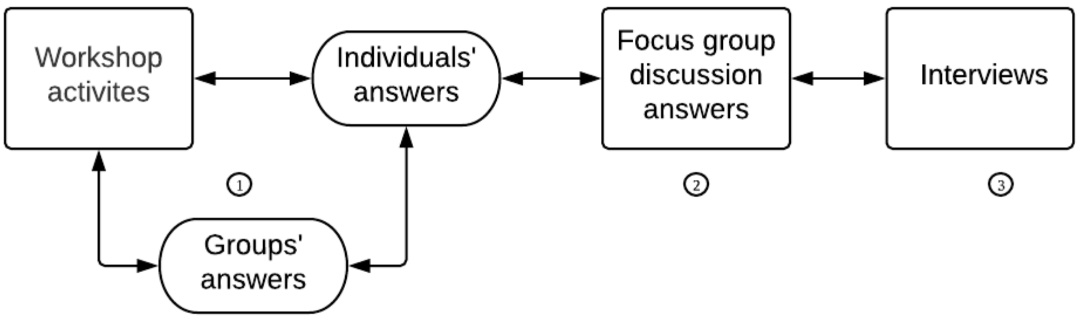


Figure 5.7 Triangulation of teachers' answers in three stages

The answers may be classified as stemming from the pre-stage (the first stage) or the post-stage (the later stage); the questions were presented differently in each stage, but they comprised the same core information. This approach also aided the tracking of conceptual change in the teachers' answers (Figure 5.7).

Triangulation to validate the findings of the review of three sources of students misconceptions

The findings of the review of textbook content (Section 7.1, Chapter 7) were triangulated against the students' answers in the pilot study (see Figure 5.8), and pre-test and post-test. The triangulation involved linking students' erroneous (misconceptions) to the possible source of these misconceptions, which is the textbook. In contrast to triangulation teachers' answers in the Workshop, focus group discussions and the interview, in which concealed cases or information was matched, this type of triangulation entailed examining items/answers that are identical across the data sources.

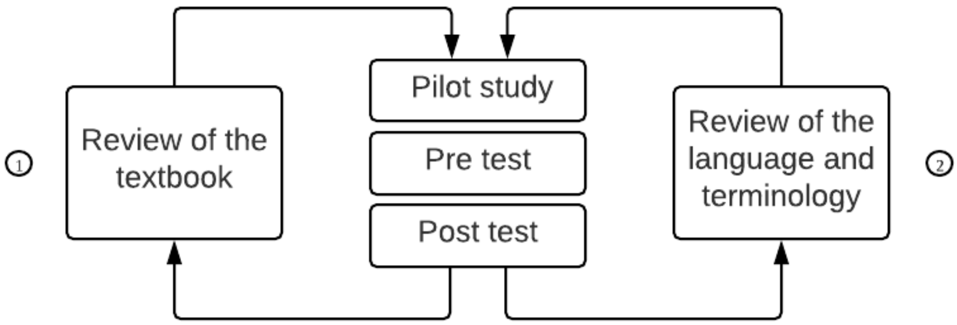


Figure 5.8 Triangulation process for validating the findings of two sources of students' misconceptions.

The results of the language and terminology review were triangulated against the students' errors in the pilot study, pre-test and post-test. Similar to the workshop findings and review of the textbook finding triangulations, this type of triangulation was a cause-and-effect approach, which indicated language and terminology as the external drivers of the students' answers. As stated in Chapter 7, this triangulation linked scientific language, Modern Standard Arabic and vernacular language.

In brief, conceptual change is likely to occur if the faulty information in the reviewed textbook and its language are corrected. Dissatisfaction with old concepts can then be stimulated through prompt questions, such as 'From where did you obtain this idea? It is not found in the textbook'. In most of the reviewed cases, however, the students found support for their ideas in the textbook, or their language. That is, the ideas that they hold are not merely personal beliefs but ones backed by scientific information.

5.8 Summary

This chapter focused on the methodology that was designed and used to collect, analyse, and interpret the data. The methodology was structured in a way that enabled illumination of Research Questions 1–4. To this end, the TCE was administered to students to measure their misconceptions (addressing Research Questions 1 and 2), and the Science Teachers' Professional Development Workshop questionnaire was administered to the teachers to measure their misconceptions and their responses to conceptual understanding. The workshop was designed to prevent direct exposure of the teachers to the items in the TCE before it was administered to students. The teachers' conceptual understanding was monitored by comparing the answers derived from them through different avenues (i.e. the workshop training sessions, the focus group discussions, and the interviews), whereas the students' conceptual understanding was monitored through their responses in the pre-tests and post-tests. Research Question 4 was addressed by examining the Saudi physics textbook and the contribution of language and terminology in the formation of students' misconceptions. Several tools were adopted to facilitate instant analyses of the data, and a combination of qualitative and quantitative analyses was performed. Triangulations were carried out to link the student misconceptions found in the data collected as responses to Research Questions 1–3 to the misconceptions possible sources identified as responses to Research Question 4.

CHAPTER 6
DATA ANALYSIS

6.1 Introduction

Dealing with conceptual change in students' old beliefs requires measuring their misconceptions before and after instruction. For this purpose, two sources of data were used. The first is the Thermal Concept Evaluation (TCE) instrument, which was intended to assess students' level of understanding of thermal concepts in everyday contexts. Accordingly, Research Questions 1 and 2 were formulated to identify how Saudi students responded to conceptual change teaching regarding their unscientific conceptions. The results of the TCE instrument are analysed in this chapter. Research Question 3 regarding teachers' conceptual understanding of thermal energy concepts has been investigated using the data collected from the second source of data—the Science Teachers' Professional Development Workshop—which was designed to evaluate teachers' level of understanding of thermal concepts. The data in this chapter were collected according to the methodology discussed in Chapter 5.

Section 6.2 discusses the descriptive statistics related to TCE results, including the difficulty index, test reliability, and TCE individual item analysis. Section 6.3 is oriented towards answering Research Question 1, Section 6.4 covers Research Question 2, and Section 6.5 discusses Research Question 3.

6.2 Descriptive Statistics

The TCE pre-test results of the 742 students were examined on the basis of mean and standard deviation (SD) values, the reliability of the pre- and post-TCE instrument and the comparison of total pre- and post-TCE results (see Appendix F) as well as the frequencies of students answers also has been calculated using SPSS (see Appendix G). The results are listed in Table 6.1, which shows that the mean scores of the students in the pre-test ranged from 3.69 to 5.84 out of 26 and that their mean scores in the post-test ranged from 5.02 to 7.23. For School 2, whose teacher did not attend the Workshop, the students' mean on the post-test was less than on the pre-test. In addition, data for school #6 been deleted. Because with very small sample sizes, Mann-Whitney U test have to be used for the analysis.

Table 6.1 *Means and SDs and t-Test Results (the maximum possible score is 26 points, each question donates one point)*

School	No. of students[9]	Pre		post		Effect size (Cohen's d)	t-value
		Means	SD	Means	SD		
2	51	5.84	2.49	5.02	3.27	*…	*…
3	73	5.36	1.95	6.01	1.90	0.34	**2.017
4	558	5.78	2.62	6.20	2.36	0.17	***2.993
7	47	4.98	2.07	6.49	2.73	0.62	***2.912

Note: Cohen value can not be calculated
*Note: **p < 0.05, ***p < 0.01*

6.2.1 *Difficulty Index*

Item difficulty can range from 0.0 (No student answered an item correctly) to 1.0 (All students answered an item correctly). The lower the item difficulty, the more difficult an item is for students. As illustrated in Figure 6.1, the main study analyses showed that for 14 items in the pre-test and 12 items in the post-test, the difficulty index was less than 0.20. In other words, the test was excessively challenging relative to the overall ability of the class. Only a few items were easy for the students. As mentioned

[9] This is referring to the number of students who agreed to complete the pre- and post-tests, not the number of students enrolled in a school

before, a low difficulty index is most of the time associated with misconception diagnostic tests because these inventories are either too hard or too easy for students to complete (Prince et al., 2012).

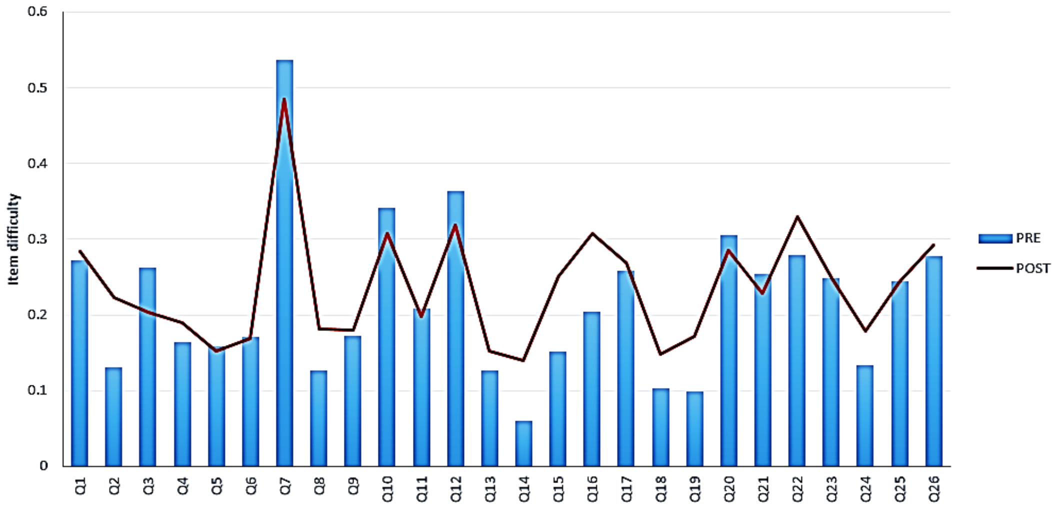


Figure 6.1 Item difficulty of the pre- and post-tests of TCE.

6.2.2 ***Test Reliability***

The Kuder–Richardson 20 coefficient (KR20) is used to measure the internal consistency for measures with dichotomous choices. Kuder–Richardson 20 is a special case of Cronbach Alpha used to measure test reliability coefficient if the responses to the test consist of 1 and 0 (i.e. true/false or yes/no) (Kazak et al., 2018). Table 6.2 shows that, even though the reliability coefficient derived in the pilot study was 0.5, the main study revealed a low reliability for the pre- and post-tests (i.e. .36 and .24, respectively).

Table 6.2 *TCE Pre-Test and Post-Test reliability and Mean Values*

Value	Pre-test	Post-test
Cronbach Alpha	.36	.24
No. of items	26	26
Mean	5.65	6.14

However, the mean score increased from 5.65 in the pre-test to 6.14 in the post-test. According to Prince et al. (2012), low test reliability is likely to be achieved for concept inventories because their contents are either too difficult or too easy for students to understand. Padalkar (2010), who conducted a cross-cultural study in India, found that determining test reliability is difficult in a cross-cultural context where many factors are involved. To address this issue, Padalkar interpreted reliability qualitatively through the consistency in students' answers to the same question groups and the frequency of incorrect responses rather than interpreting it on the basis of exact percentages. The author also found a pattern in students' scientific and non-scientific answers.

6.2.3 *Individual Item Analysis*

In the present study, reliability can be deduced from the patterns that underlie the scientific and non-scientific answers. In the same vein, Table 6.3 shows that the number of correct and incorrect answers in the pre- and post-tests is almost the same, with 15 questions has slight improved regarding the percentage of students who gave correct answers in the post-test. The percentage of correct responses derived on the basis of pure random guessing was expected to reach 20% as its states by Doran and Pella (1970). Thus, in this analysis, only answers with population 20% and over is considered as a misconception. In addition, question 7, which centres on the final temperature of a mixture of unequal amounts of water at different temperatures, was the only question for which the percentage of correct answers was higher than those of the misconceptions.

Table 6.3 *Correct responses (%, red Highlight), incorrect responses (%, grey Highlight)*

Question options	Pre-test					Post-test				
	A	B	C	D	E	A	B	C	D	E
Q1	27	59	7	7	0	28	54	7	11	0
Q2	5	13	60	23	0	10	22	45	22	0
Q3	8	26	37	29	0	10	20	39	31	0
Q4	9	16	20	55	0	18	19	22	42	0
Q5	6	16	41	38	0	14	15	43	28	0
Q6	15	17	26	42	0	19	17	26	38	0
Q7	8	14	54	24	0	13	17	49	22	0
Q8	13	36	41	11	0	18	34	37	11	0
Q9	13	17	13	37	20	18	18	18	30	16
Q10	39	7	34	20	0	32	14	31	23	0
Q11	9	21	19	16	35	17	20	20	17	26
Q12	18	37	36	8	0	25	34	32	9	0
Q13	49	29	10	13	0	44	28	13	15	0
Q14	32	6	7	55	0	38	14	13	35	0
Q15	27	15	25	33	0	29	25	25	21	0
Q16	20	31	24	12	14	31	26	23	11	9
Q17	26	18	40	17	0	27	31	28	15	0
Q18	31	41	6	10	11	24	39	14	15	9
Q19	10	47	24	20	0	17	41	24	18	0
Q20	12	16	31	42	0	20	18	29	33	0
Q21	15	31	29	26	0	25	28	24	23	0
Q22	30	21	26	24	0	33	24	24	20	0
Q23	8	13	25	55	0	15	17	25	43	0
Q24	18	32	37	13	0	24	26	33	18	0
Q25	13	29	24	33	0	18	31	24	27	0
Q26	7	5	51	10	28	14	10	36	11	29

Note. All percentage numbers has rounded up to the nearest decimal point. This caused the sum of each question respondents not necessarily =100%.
Note. The maximum possible score is 26 points, each question donates one point

Figure 6.2 illustrated the percentage of Saudi female students misconceptions of Thermal Concept Evaluation (TCE) for the four categories as listed by Yeo and Zadnik (2001, p. 498). The percentage of misconceptions remained almost the same among the pilot study, pre-test and post-test participants over almost all the four categories, with a slight decline in these misconceptions among students in the post test.

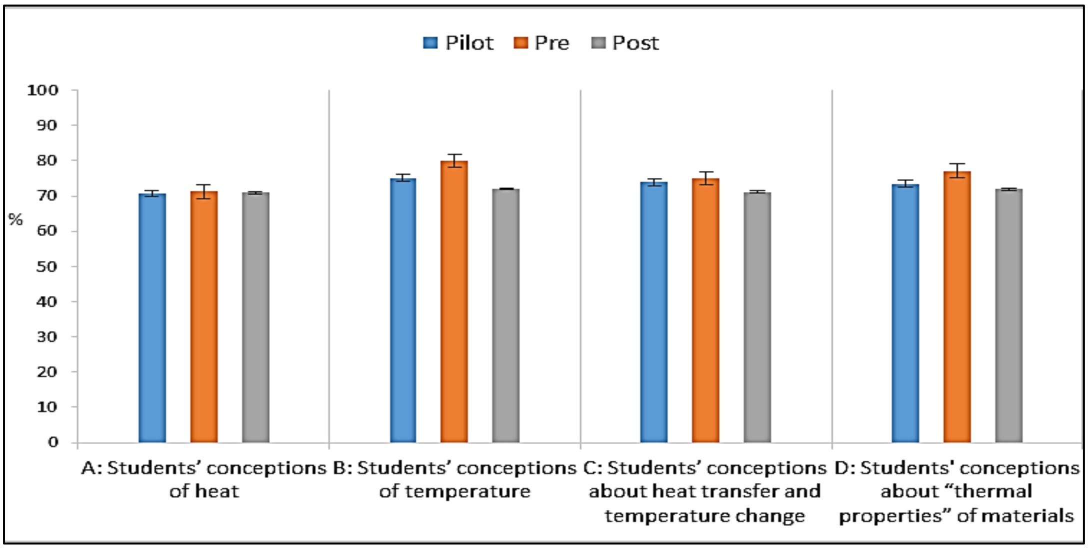


Figure 6.2 Saudi female students' misconceptions percentage

Table 6.4 shows that the highest improvement in responses was observed for Question 16 which revolves around heat conductivity, with the number of scientific answers to the question increasing by 11%. The second highest improvement was observed for Question 15 revolves around the likely temperature of a mixture of water and ice for which the students registered a mean improvement of 10%. This is followed by Question 2 which revolves around the temperature of ice water, for which the students exhibited a mean enhancement of 9%.

Table 6.4 *The percentage of improvement of some of the Saudi Students scientific thermal conceptions' (correct answers)*

Q	TCE question	Increased by %
Q2	Ken takes six ice cubes from the freezer and puts four of them into a glass of water. He leaves two on the countertop. He stirs and stirs until the ice cubes are much smaller and have stopped melting. What is the most likely temperature of the water at this stage?	9%
Q15	A group is listening to the weather forecast on a radio. They hear: "… tonight it will be a chilly 5°C, colder than the 10°C it was last night."	10%
Q16	Kim takes a metal ruler and a wooden ruler from his pencil case. He announces that the metal one feels colder than the wooden one. What is your preferred explanation?	11%

Moreover, Table 6.5 shows that, out of 26 questions, eight (i.e. Q3, Q5, Q7, Q10, Q11, Q12, Q20 and Q21) were which the correct answers percentage declined in the post-test. The highest decline, 6%, was observed for Question 3, followed by question 7 which declined by 5% in the post test. Question 3 asks about the likely temperature of ice cubes in a mixture of ice and water. In addition, the percentage of the correct answers of questions 6, 23 and 25 remains the same in both in the pre- and post-tests (there was no change in the correct answers percentage after the post-test).

Table 6.5 *The highest decline in the percentage of the correct answers in TCE*

Q	TCE question	Declined by %
Q3	The ice cubes Ken left on the counter have almost melted and are lying in a puddle of water. What is the most likely temperature of these smaller ice cubes?	6%
Q7	Lee takes two cups of water at 40°C and mixes them with one cup of water at 10°C. What is the most likely temperature of the mixture?	5%

On the other hand, Table 6.6 shows that out of 26 questions, 17 which received the same dominant misconceptions in the pre- and post-tests, where students kept their misconceptions after the instruction. These questions are Q1-Q8, Q10, Q13, Q15-Q16, Q18, Q22-Q23, Q25 and Q26), in which these incorrect answers can be considered as a robust misconceptions. Question 15, which asks whether 5°C is twice as cold as 10°C or not, was provided three dominant misconceptions.

Table 6.6 *An example of dominant misconceptions in pre and post-test of TCE*

Q15. A group is listening to the weather forecast on a radio. They hear: "… tonight it will be a chilly 5°C, colder than the 10°C it was last night."			
Misconception options	a. Jen says: "That means it will be twice as cold tonight as it was last night."	c. Raj says: "It's partly right, but she should have said that 10° C is twice as warm as 5°C."	d. Guy says: "It's partly right, but she should have said that 5° C is half as cold as 10°C."
Pre	27%	25%	33%
Post	29%	25%	21%

Furthermore, there was 9 questions out of 26 where students changed their misconceptions in the pre-test to either a new misconception (i.e. Questions 9, 11, 12, 17, 20 and 21) or they shifted from an misconception to a correct one (i.e. Questions 19 and 24) in the post-test. This means the percentage of the alternative ideas in the post-test decreased and the percentage of the scientific ideas (correct answer) increased in the post test. In other words, more students migrate towards the correct answers (see Table 6.3).

In responding to research questions one and two, the students' answers in the TCE instrument were analysed using quantitative analysis approach. The analysis revealed almost no change in the students' level of understanding of thermal concepts before and after instruction. Next, the research question responses are individually explained using the qualitative analysis of different materials such as language, and textbook.

6.3 Research Question 1

What thermal concepts are understood scientifically by Saudi female high school students before and after instruction?

Due to language barriers, Saudi students understand scientific language after it has gone through three mediums: translated scientific language, Modern Standard Arabic and vernacular language. Conceptual change has to occur in every one of these barriers and not only in the final product. A simple concept, such as Heat, has deep underlying structures that may prevent the accommodation of new schemas. Figure 6.3 illustrates all the steps necessary to replace old schemas; the accommodated concept in each stage was tested to determine which barrier is active. In Figure 6.3, loop ① represents the entire process of learning intended concepts (i.e. to-be-learned concepts or new schemas). Loop ② represents a scenario wherein the intended concepts remain uncomprehended after passage through the three languages, thus they go through this revision loop, where students attempt to understand the concept using different content's source that is related to the same concept and may be found in the three languages. Loop ③ denotes the sub-loops used to test conceptual change occurrence through the measurement of students' understanding every time they deal with new phenomena or new events related to the same concept. Students vary in the speed with which they can interpret concepts delivered through the three languages. Some students may spend a lifetime endeavouring to understand a concept, whereas others may do so in the blink of an eye.

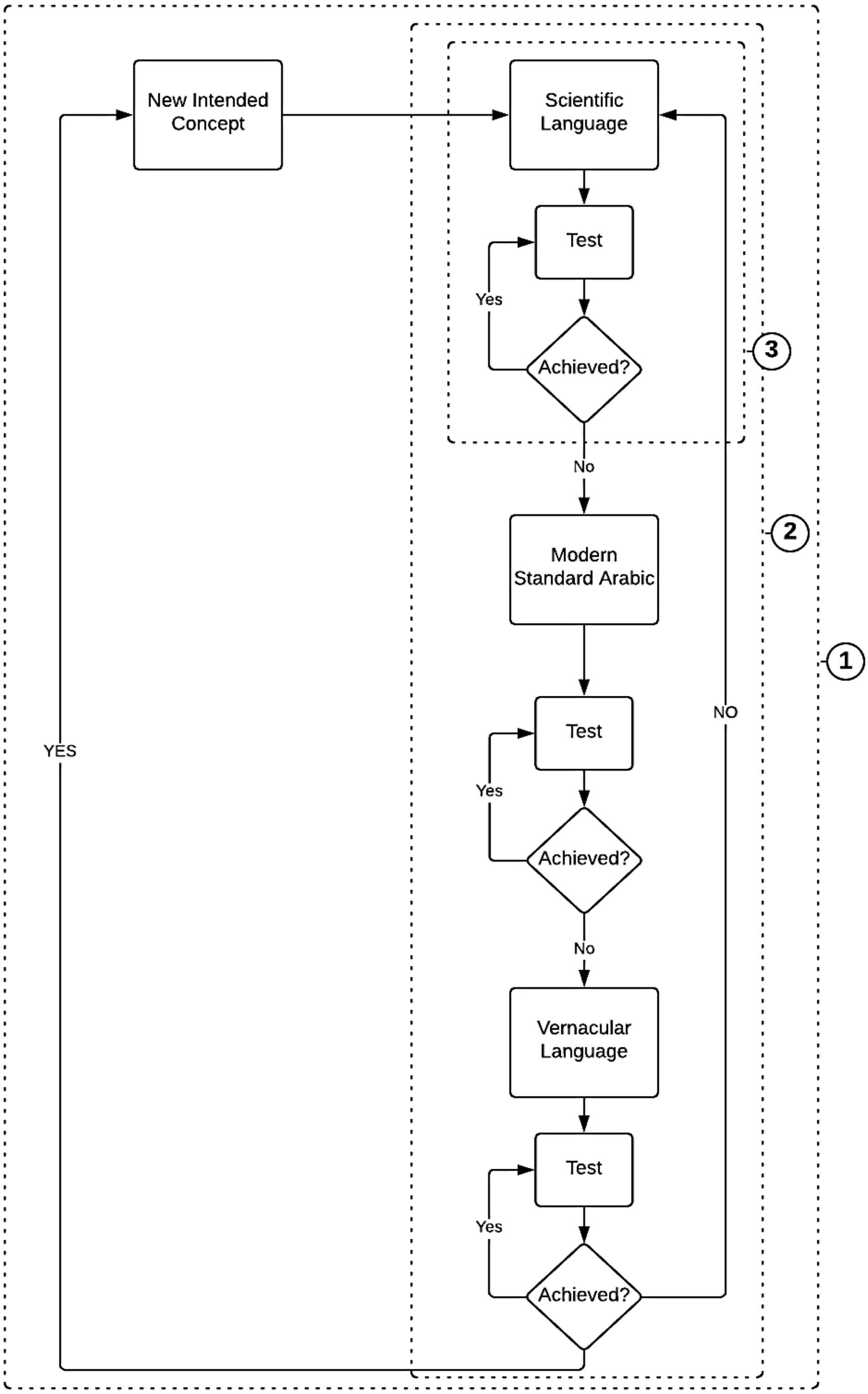


Figure 6.3 Intended/accommodated concept loops via language barriers.
<u>Key</u>: ➀ Intended-accommodated loop, ➁ Revision loop, ➂ Testing loop

Understanding this situation may help elucidate the limited number of thermal concepts that are scientifically understood by Saudi female students following instruction. For instance, for conceptual change to occur and for students to consequently comprehend the scientific thermal concept that says the ‘boiling point is not the maximum temperature a substance can reach’ (the new schema), the non-scientific thermal concept that states the ‘boiling point is the maximum temperature a substance can reach’ (the old schema) must be removed after it has been examined and filtered through multiple barriers. As previously stated, crossing each barrier necessitates two conditions: Students must know what is wrong with the old schema, and they must be knowledgeable about the new one (Chi, 2013). In each stage, as well, the level of satisfaction with the old schema must be at its lowest point, and satisfaction with the new schema must be at its highest; this can be achieved by demonstrating the new schema’s intelligibility, plausibility and fruitfulness (Duit et al., 2008; Posner et al., 1982).

Table 6.7 illustrates language barriers that may prevent the conceptual change necessary to accommodate the new schema (i.e. ‘Boiling point is not the maximum temperature a substance can reach’) and shows how each language presents the same information. The first barrier, which is the difficulty experienced by students in arriving at the conclusion that the ‘boiling point is not the maximum temperature a substance can reach’ on the basis of the numerous mathematical concepts in their Saudi physics textbook. The second barrier, Modern Standard Arabic, which explains how this barrier prevents student from undergoing conceptual change by providing incorrect, mistranslated and misleading information. For the third barrier, in the participants’ vernacular language, the concept of temperature does not exist, thus apparently driving them to use coal temperature as a reference temperature.

Table 6.7 *An example of language barriers between the old schema (To-be-changed concept) and the new schema (To-be-learned concept)*

To-be-learned concept	Language barriers			To-be-changed concept
	Scientific*	Modern**	Vernacular***	
Boiling point is not the maximum temperature a substance can reach.	Atmospheric pressure is about 10 N per 1 cm^2 (10^{-4} m^2), which is about 1.0×10^5 N/m^2 or 100 kPa(Zitzewitz, 2005).	The higher the atmospheric pressure, the greater the boiling value of the substance(Abu-Wardah, 2016).	1. I wait for it on something hotter than coal (waiting impatiently). 2. He is hotter than coal (He is very impatient.).	Boiling point is the maximum temperature a substance can reach.

*Scientific language ** Modern Standard Arabic *** Vernacular language

By saying ‘hotter than coal’, they mean that the temperature of coal is the ultimate temperature of all substances they know and that nothing can be found beyond this temperature, unless the statement is used to denote someone who is waiting impatiently (exaggeration). To measure the comprehension of intended concepts, students need to demonstrate awareness of new beliefs after studying thermal content for several weeks. This goal was intended to be achieved through question 19 of the TCE instrument as it shows in Table 6.8.

Table 6.8 *TCE question used to examine the effectiveness of replacing the old schema (To-be-changed concept) with the new schema (To-be-learned concept*)

To-be-learned concept	TCE question	To-be-changed concept
Boiling point is not the maximum temperature a substance can reach.	Q19. Ron reckons his mother cooks soup in a pressure cooker because it cooks faster than in a normal saucepan but he doesn’t know why (Yeo & Zadnik, 2001, p. 498).	Boiling point is the maximum temperature a substance can reach.

After instruction between the pre- and post-tests, an improvement of only 7% was achieved in terms of the number of students who believe that the ‘boiling point is not the maximum temperature a substance can reach’. This situation seems more than a common error issue. Teachers who lack understanding of how conceptual change can occur and how their students process new information may make no difference in student achievement before and after instruction (Duit et al., 2008). To achieve the intended conceptual change and to enable new schemas to take the place of old ones, conceptual change must run smoothly from one stage to another, crossing all barriers. Any faulty contents found in any of these stages may induce the formation of new schemes as false beliefs or flawed knowledge, induce strong attachment to old schemas or cause the assimilation of new schemas.

To sum-up, as demonstrated in this section, Saudi students exhibit a limited understanding of thermal concepts, as evidenced by the near-lack of difference in the results of the pre- and post-tests. Level of understanding is associated with language barriers, but it is also connected to teachers' lack of knowledge regarding conceptual change and how it works as mentioned by Duit et al. (2008), the types of errors that students commit and the drivers of these errors. Learning and teaching that totally rely on memorising figures and reciting physics concepts from a textbook word by word may confront students with challenges in applying what they have been memorising as daily life events.

6.4 Research Question 2

What misconceptions are formed by Saudi female high school students about thermal energy before and after thermal energy instruction?

Four categories of thermal concepts are undertaken in the TCE instrument: students' conceptions of (A) heat, (B) temperature, (C) heat transfer and temperature change and (D) thermal properties of materials (Yeo & Zadnik, 2001). The students' misconceptions before and after instruction were measured in relation to those four categories. Some misconceptions in each category were selected to illuminate how students respond to conceptual understanding questions. According to Chi (2013), four types of mental models can explain why conceptual change can be challenging; these are i) false beliefs, ii) flawed mental models, iii) category mistakes schemas and (iv) missing schemas which were discussed in Chapter 4 Section 4.4.

A close examination of the students' errors in the TCE, indicates that students with the highest percentage of incorrect options who changed their incorrect answers after the instruction, either retained their misconceptions (i.e. Q15, Q17 and Q22) or shifted to new misconception (i.e. Q14 and Q25). Keeping an old schema or changing it can be interpreted in numerous ways, thus highlighting the need to separately investigate each case. For instance, a shift from an old schema to a new one depends on the old schema category. Some schemas are false beliefs, which are regarded in Chi's (2013) mental model categories as the errors that are the most receptive to conceptual change through either explicit or implicit refutation. Other schemas belong to more advanced mental models, such as Category mistakes schemas or missing schemas. If students modify their errors from simple to more advanced mental models, this may mean that instruction somehow confused the students or compelled them to increase their level of satisfaction with an old schema by elevating it to a new and more robust level (Duit et al., 2008) because of, for instance, the difficulty of comprehending a new schema. Students' alteration of schemas from a robust level of their mental models to less robust ones suggests an improvement in understanding, which can be further enhanced in later years or classes. Table 6.9 illustrates that students shifted their schemas from advance ones (i.e. category mistakes) in two questions which are Question 14 that revolves around particular materials' temperature, and question 25 that revolves around heat transfer and temperature change.

Specifically, Table 6.10, illustrates that the misconception that 'The boiling point of water is 100°C (only)' (see Yeo & Zadnik, 2001, p. 498), received up to 91% of the students' responses in the pre-test of Question 19 and 88% of the students' responses to Question 8 and 55% of Question 4 respondents. This misconception also received the highest percentage of students' answers in the post test, where its received 83%, 82%, and 42% in the post test of question 19, 8 and 4 respectively. Which suggested that this misconception is the strongest misconceptions held by these Saudi female students. As can be seen in Table 6.10, the second misconception that received the highest percentage of students answers was 'Boiling point is the maximum temperature a substance can reach' (see Yeo & Zadnik, 2001, p. 498), which received up to 90% and 83% of pre and post of students' responses to Question 19.

Table 6.9 *Saudi students misconceptions' (old schemas) as mental models (MM)*

Misconception	TCE question	Associated options		%		MM	
		Pre	Post	Pre	Post		
Heat is a substance	Q22. When Zack uses a bicycle pump to pump up his bike tires, he notices that the pump becomes quite hot.	c. Heat flows from his hands to the pump	b. Temperature has been transferred to the pump.	26%	24%	CM	CM
Heat and temperature are the same thing	Q15. A group is listening to the weather forecast on a radio. They hear: '… tonight it will be a chilly 5°C, colder than the 10°C it was last night'.	d. Guy says: "It's partly right, but she should have said that 5° C is half as cold as 10°C."	a. Jen says: "That means it will be twice as cold tonight as it was last night."	33%	21%	FB	FB
Temperature is a property of a particular material or object.	Q14.Jan announces that she does not like sitting on the metal chairs in the room because 'they are colder than the plastic ones'.	d. Mai says: "They are colder because metal has less heat to lose than plastic."	a. Jim agrees and says: "They are colder because metal is naturally colder than plastic."	55%	35%	CM	FB
Heat flows more slowly through conductors making them feel hot	Q25. Gay is describing a TV segment she saw the night before: "I saw physicists make super-conductor magnets, which were at a temperature of –260°C."	d. Gay is not sure: "I think super-conductors are good heat conductors so you can't cool them to such a low temperature."	b. Kay disagrees: "Yes you can. There's no limit on the lowest temperature."	33%	27%	CM	FB
Materials like wool have the ability to warm things up.	Q17. Amy took two glass bottles containing water at 20°C and wrapped them in washcloths. ….The most likely room temperature…..	c. 20°C	b. 21°C	40%	28%	FB	FB

Note. CM= Category Mistakes, FB= False Beliefs

Table 6.10 *Misconceptions that received highest responses percentage and linked questions options' associated with these misconceptions (continued)*

Misconceptions*	MM	Option**	Pre %					Post %				
A: Heat												
1.Heat is a substance	CM	10a,22c	39	26				32	24			
2.Heat is not energy.	CM	22b,c,d	70					67				
3.Heat and cold are different.	FB	10a,13b,18a,23a,b,24a,b	39	29	31	21	50	32	28	24	32	50
4.Heat and temperature are the same thing.	FB	15a,c,d,18a,e	85	42				75	33			
5.Heat is proportional to temperature.	FB	7d, 11c,15a,c	24	19	52			22	20	54		
6.Heat is not a measurable.	FB	7a	8					13				
B: Temperature												
7.Temperature is the "intensity" of heat.	FB	15a,c,d	85					75				
8.Skin or touch can determine temperature.	FB	16c	24					23				
9.Perceptions of hot and cold are unrelated to energy transfer.	FB	21a,b, 22b,c,d	46	71				53	68			
10.When temperature at boiling remains constant, something is wrong.	FB	5c,d	79					71				
11.Boiling point is the maximum temperature a substance can reach.	FB	19b,c,d	90					83				
12.A cold body contains no heat.	FB	7a,b,10b,11d,22c,d, 26c	22	7	16	50	51	30	14	17	44	36
13.The temperature of an object depends on its size.	FB	1d, 9e, 14c	7	20	7			11	16	13		
14.There is no limit on the lowest temperature.	FB	25a,b	42					49				
C: Heat transfer and temperature change												
15.Heating always results in an increase in temperature.	FB	3c,d 4c, 5c,d	66	20	79			70	22	71		
16.Heat only travels upward.	FB	20a	12					20				
17.Heat rises.	CM	20a	12					20				
18.Heat and cold flow like liquids.	CM	10d, 13b	20	29				23	28			
19.Temperature can be transferred.	CM	13a, 22b	49	21				44	24			

Misconceptions*	MM	Option**	Pre %				Post %			
20.Objects of different temperature that are in contact with each other, do not necessarily move toward the same temperature.	FB	1c, 9a, 17c, 24b,c	7	13	40	69	7	18	28	59
21.Hot objects naturally cool down, cold objects naturally warm up.	FB	3a, 13c	8	10			10	13		
22.Heat flows more slowly through conductors making them feel hot.	CM	25d	33				27			
23.The kinetic theory does not really explain heat transfer.	FB	20b,21d	16	29			18	24		
D: Thermal properties of materials										
24.Temperature is a property of a particular material	CM	9d,14a, 16b,c, 24a,b,c	37	32	55	87	30	38	49	83
25.Metal has the ability to attract, hold, or absorb heat and cold.	CM	9c, 14d, 16d	13	55	12		30	35	11	
26.Objects that readily become warm do not readily become cold.	FB	25d	33				27			
27.Different materials hold the same amount of heat.	FB	11c , 14d, 24c	19	55	37		20	35	33	
28.The boiling point of water is 100°C only.	FB	4d,8b,c,d, 19b,c,d	55	88	91		42	82	83	
29.Ice is at 0°C and/or cannot change temperature.	FB	1b	59				54			
30.Water cannot be at 0°C.	FB	2c,d, 11e	83	35			67	26		
31.Steam is more than 100°C.	FB	6c,d	68				64			
32.Materials like wool have the ability to warm things up.	CM	17b,23b	18	13			31	17		
33.Some materials are difficult to heat.	FB	26a,b,c	63				60			
34.Bubbles mean boiling.	FB	8d	11				11			
35.The bubbles in boiling water contain air, oxygen, or nothing.	FB	12a,b,d	63				68			

Note. MM= mental module, CM= Category Mistakes, FB= False Beliefs

** This column taken from Yeo and Zadnik (2001)*

*** This column taken from Louzada et al. (2015)*

The third misconception that received the highest percentage of students answers that ‘Temperature is a property of a particular material’, which was reflected in up to 87% of the students’ responses to Question 24 and 55% of Question 16 respondents. Furthermore, ‘Heat and temperature are the same thing’ and ‘Temperature is the “intensity” of heat.’ attracted the same percentage (85%) of Question 15 students’ responses in the pre-test and post-test. In addition, that ‘Water cannot be at 0°C’ received 83% and 67% of students’ responses of Question 2 in the pre and post-test respectively. All those five misconception examples that received the highest percentage of students’ responses are false belief schemas. There was only one misconception that belong to category mistake that ‘Temperature is a property of a particular material or object’ received high percentage of students responses in the pre and post-test to Question 24. In general, category mistakes conception were less attracted by Saudi female high school students.

According to Chi (2013), false beliefs schemas are relatively easy to correct using explicit or implicit refutation. Students’ response to Question 2 of the TCE—‘Water cannot be at 0°C’—as an example. A possible explicit refutation of the statement can by indicating that the statement is un-true and that water can have a temperature of 0°C, and possible implicit contradiction can take the form ‘At zero degrees, a mixture of ice and water can be formed’. An important requirement, however, is that amendments to false beliefs schemes be supported by an experiment, a discussion of certain phenomena in nature or worksheet exercises that include relevant information from a textbook. An example of Category mistakes schemas is the case of the students who believe that ‘heat is a substance’, as reflected by their choice of option (c) as a response to Question 22 (Table 6.10). This option, ‘heat flows from his hands to the pump’, referring to heat as an entity instead of a process (Chi, 2013; Yeo, 2002). In this case, the students' misconceived heat as a type of entity (Chi, 2013)—an old belief that may date back to early caloric theory (Horikoshi, Schiffmann, Fukushima, & Serpone, 2018).

Chi (2013) stated that Category mistakes schemas are a serious condition because entities and processes have no common dimensions. Moreover, entities belong to an ontological tree, thereby rendering them difficult to correct through simple explicit or implicit refutation strategies. Chi (2013) claimed that miscategorising old schemas, such as naïve ideas, into inappropriate ontologically trees causes such incorrect notions to be robust (Figure 6.4). Correction therefore requires a categorical shift using alternative categories, which themselves need considerable attention when created. A categorical shift however, necessitates that students recognize an old category to be wrong and that they have knowledge of the correct category (Chi, 2013). Without these conditions, conceptual change will not take place.

Another example of a Category Mistake is 'temperature has been transferred to the pump' (see Yeo & Zadnik, 2001, p. 498). The majority of the respondents to question 22 chose option B, which associated with this misconception an error that cannot be contradicted through explicit or implicit refutation. Direct explicit refutation would take the form 'temperature hasn't been transferred to the pump' or '<u>heat</u> has been transferred to the pump', but this type of correction will not help students correct their schemas because both statements belong to different dimensions. That is, the statements are incommensurate.

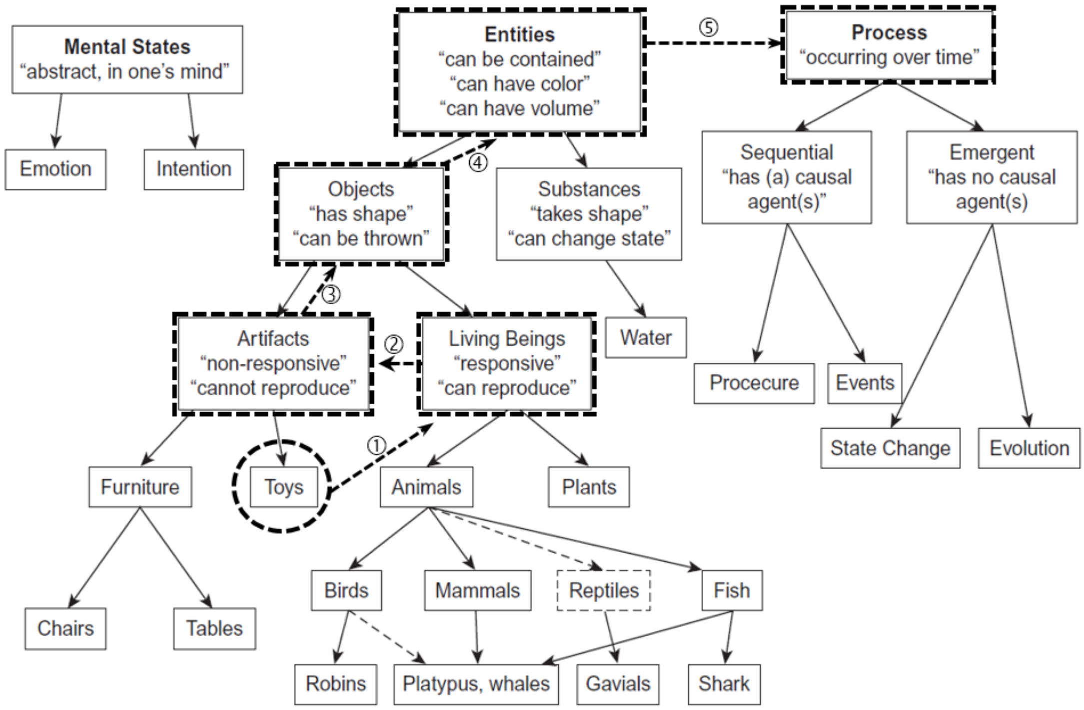


Figure 6.4 Steps to change one of students beliefs (i.e. Q26) through the ontological trees*

**"Reproduced from Chi (2013) with the permission from the author"*

Even though most students' errors in answering thermal questions are due to misconceived knowledge, wherein heat and temperature are miscategorised in an ontological tree as entities, the errors may be distributed over multiple ontological trees (Chi 2013; Yeo, 2002). Figure 6.4 illustrates that students participating in this work miscategorised some objects that are considered *artefacts* under the *living beings* category and accordingly ascribed the features of living beings to these artefacts. In doing so, the students formulated incorrect predictions and explanations. A case in point is their response to Question 26 in the TCE, where they miscategorised *dolls*, which are artefacts, as living beings. All their predictions and explanations correspondingly revolved around this misunderstanding. One of the explanations given for the response was 'It's because the dolls were made of material which did not hold heat well'. Correcting the explanations requires multiple steps. First, the doll category must be removed from the living beings category and classified under the artefacts category, after which the heat category must be shifted from entity to process in ontological trees.

In short, as can be seen, the Saudi students formed multiple thermal-related misconceptions, and there was almost no change in these notions before and after instruction. The conceptual change approach can be effective only if students know about their faulty ideas and are knowledgeable about correct ones. With these conditions satisfied, instructors can decrease the level of satisfaction with an old schema and increase satisfaction with a new one. In this process, an essential requirement is to treat every thermal misconception case individually given the nature of thermal concepts, that is, their descending submergence in ontological trees. Correspondingly, some misconceptions require extensive discussion.

6.5 Research Question 3

What is the level of thermal conceptual understanding exhibited by Saudi female high school teachers?

The conceptual change approach deals with challenging individuals' learning of new schemas that do not initially align with modern scientific theories. An essential step in this process is examining individuals' new schemas after instruction that is meant to challenge their beliefs. To this end, 30 female high school physics teachers were interviewed. As reflected in Table 5.2, the Workshop was designed in such a way as to prevent the direct exposure of the teachers to the TCE instrument questions and provide the teachers with all essential information that can help them change their and their students' old schemas. Conceptual change among the students were measured using Yeo and Zadnik (2001) TCE instrument, but such measurement on the part of the teachers was implemented through the focus group discussion and individual interviews.

For instance, in order to reach the new schema that ‘the bubbles in boiling water do not contain oxygen or hydrogen gas’, multiple attempts were made to ensure that the teachers changed the old schema that the bubbles in boiling water do contain oxygen. In the first attempt, shown in Table 5.2, teachers asked about the chemical bonds between and inside water molecules. They were also asked about the components found in the bubbles created from boiling water as an open ended question, without being offered leading answer options. In the second attempt, by explaining the types of chemical bonds between and inside water molecules and the difference between intermolecular bonds and covalent bonds, it was assumed that the teachers would conclude that water do not decompose to hydrogen and oxygen by boiling. Thus, the old schema that suggests that there is oxygen inside boiling water bubbles is not true. In the third attempt, by discussing the question of whether water vapour is a liquid or gas, it was assumed that the teachers would conclude that just because water is in a gaseous state does not mean that it has turned to oxygen and hydrogen gas.

However, the workshop open-ended question revealed that of the 30 teachers in the group, 29 of them responded that air is found in boiling water bubbles. Only one teacher responded with ‘water vapour’. The teachers’ responses also showed that out of 25 participants, six identified oxygen and hydrogen as boiling water bubble components, 10 stated that nothing is found in the bubbles and eight indicated that air is a component. Only one participant identified vapour as a component of the bubbles. Among all the responses, 40% of the teachers believed that oxygen and hydrogen can be found in the bubbles. The teachers also struggled to determine the reason why heat can break intermolecular bonds in water and consequently convert it from one state to another, but it cannot break water's covalent bonds, thereby enabling water to contain oxygen and hydrogen. In addition, an analysis of the Workshop data revealed that a huge number of the participating teachers believed that cold objects do not contain heat. This may be a matter of terminology—'zero' translated to the Arabic language means 'empty' or 'nothing'.

6.5.1 *Teachers' Misconceptions as A False Beliefs Schemas: Example 1*

As discussed earlier, thermal physics misconceptions vary in origin. Some are considered false beliefs schemes, whereas others are regarded as Category mistakes schemas that are rooted in ontological conceptual trees. An example of a false belief schemes is 'the boiling point of water is 100°C (only)', whose correction required several attempts (see Table 5.2 and Table 6.11). In the first attempt, the teachers were asked the following question: 'If water boils at 100°C, does it boil at 50°C?' It was assumed that raising the question will trigger the teachers' curiosity given that the two pieces of information (i.e. illogical) were juxtaposed. In the second attempt, its assumed that demonstrating 'boiling in a syringe' in an experiment adopted from FlinnScientific (2012) will lead to the conclusion that if water can boil at room temperature through a reduction in pressure, then it can do so at any other temperature by controlling the air pressure. In the third attempt, the statement was presented as a challenge, and the teachers were asked whether there is any way to make water boil and simultaneously guarantee that it does not generate enough heat that can hurt one's hand when placed in the water. Previously, the relationship between altitude and boiling point was explained to the teachers to convince them that the boiling point of a substance is not fixed but dependent on air pressure ('altitude') and substance purity.

It was assumed that the teachers would conclude that a relationship exists among altitude and boiling point of water, and that by presenting and discussing this information, the teachers would be able to help their students understand and answer the TCE instrument, particularly questions 4–6, 8 and 19.

Table 6.11 *Intended and Accommodated Concepts: False Beliefs schema*

To-be-learned concept	Workshop questions			To-be-changed concept
	1st attempt	2nd attempt	3rd attempt	
Water's boiling point is not fixed and depends on air pressure and water purity.	Water boils at 100°C. Does it boil at 50°C? [yes/no]	[Experiment: Boiling in a syringe] We did not heat the water to make it boil inside the syringe. Where did the water get the heat from? (FlinnScientific, 2012)	Did you hear about the 'ice bucket challenge'? There is another one called 'boiling water bucket challenge'. Can you put your hand in a boiling water bucket and win the challenge? [discussion]	The boiling point of water is 100°C (only).

The Workshop results showed that 90% of the teachers believe the old schema 'the boiling point of water is 100°C (only)' to be true. Three months after the Workshop, the same question, which was slightly modified from 'yes/no' form to a multiple-choice question, was presented during the focus group discussion as it can be seen in Table 6.12. The teachers appeared to struggle with processing the modified information. The participants, who responded to the question through the Poll Everywhere platform during the focus group discussion, provided variously distributed response options: 21% chose 49°C as their answer, 29% selected 50°C, 36% chose 100°C and 14% opted for 120°C.

Table 6.12 *Students and teachers answers of question regarding boiling point*

To-be-learned concept	To-be-changed concept		
Water’s boiling point is not fixed and depends on air pressure and water purity.	The boiling point of water is 100°C (Only).		
1st attempt (Focus group discussion): What is the temperature of water vapour in this case? [multiple choice]	 (google.com)	Frequent teachers’ answers %	Boiling temperature %
		21%	49°C
		29%	50°C
		36%	100°C
		14%	120°C
2nd attempt (Interview): What is the temperature of water vapour in this case?	Teacher #1	- No [water cannot boils at 50 °C]. During boiling, the temperature reaches 50 °C then surpasses this level until it reaches 100 °C. (Personal communication, March 30, 2015)	
	Teacher #24	- I chose 120 °C, but I think the temperature is less than that. The temperature written there is wrong. The picture is incorrect also because it does not show whether a stove is heating the teapot and causing it to boil. (Personal communication, March 30, 2015)	
	Teacher #41	- 100 °C or close to it. Because when water boils at 100 °C, it is converted to vapour. So, the temperature is 100 °C or a bit higher. (Personal communication, March 30, 2015)	

The correct answer is 49°C because condensed (wet) steam temperature is lower than dry steam temperature (Tlv.com, 2018). The findings indicated that 50% of the participants held onto the old schema ‘water boils at 100°C or 120°C’, whereas the rest accommodated ‘water boils at 49°C and 50°C as their new schema (i.e. Table 6.12). Teachers may have known that the boiling point of water is not restricted to 100°C but could not justify this response even after all the explanations provided to them. Thus, they accommodated only the first part of the intended concept, which is that the boiling point of water is not fixed as it can be read from the percentage of students choice 49°C, 50°C as a response (50%), and not the second part, which is that the boiling point of water depends on air pressure and water purity which can be read from teachers interview which show lack of give a reason why water may boils at a temperature that is lower than 100°C.

As presented in Table 6.10, the old schema ‘the boiling point of water is 100°C (only)’ is a type of false belief schemas, which can be refuted explicitly or implicitly (Chi, 2013). Implicit refutation appears to be insufficient to stimulate complete conceptual change for the intended concept. A more effective strategy, then, would be to use explicit and implicit refutation interchangeably. The language barriers discussed in Sections 6.2 may have been implicated in the teachers’ misunderstanding of the concept (i.e. in the participants’ vernacular language, coal temperature is the ultimate temperature of all substances.). The old schema ‘the boiling point of water is 100°C (only)’ has been embedded in these teachers’ minds for many decades and was taught this way ever since was introduced to modern female education around 60 years ago (Teacher #5, personal communication, May, 2015). People were taught that the two fixed points of water are its boiling and freezing points, and that those temperatures are fixed and do not vary at all. This has given rise to numerous intense debates among the teacher participants and their colleagues in their schools and between the participants and their educational supervisors in the Department of Education, due to the fact that the information about the fixed boiling point is listed in today’s new Saudi physics textbook as 100°C, and no other boiling point temperatures have been mentioned. Thus, teachers cannot correct the information listed in the textbook but they also forced to teach what is listed in these textbook without making any alterations. Furthermore, change in this statement may cause a huge reduction in students’ marks in the national examination which is based on the textbook, if students answered something different from textbooks. Indeed, this may increase the parents’ anger later if they found out that their children followed instructions from the teachers' and not from the textbook. This scenario has been reported in previous studies such as Qablan, Mansour, Alshamrani, Aldahmash, and Sabbah (2015) and Albadi et al. (2018). In particular, this examination issue may be what triggered teachers dissatisfaction of the new information even if it is the correct one; they have fear of the sequences. In the new version of McGraw-Hill physics textbook, the boiling point of water has been converted to Kelvins in almost the whole book and has replaced the 100˚C with 373K.

6.5.2 *Teachers' Misconceptions as A False Beliefs Schemas: Example 2*

Another example of the false beliefs schema is 'ice is at 0°C and/or cannot change temperature' (Yeo & Zadnik, 2001, p. 498) appears to have the same roots with the previous explained example 'the boiling point of water is 100°C (only)' (Yeo & Zadnik, 2001, p. 498). Older versions of Saudi physics textbooks that were used for decades indicated that boiling point (100°C) and freezing/melting point (0°C) are the two fixed points used as a reference in labelling any thermometer. These versions also provided some information about different melting point temperature and the factors that affect them. However, teachers were unable to independently justify why the ideas presented in textbooks contradict each other, wherein the melting point is described as fixed in one section of a material but indicated as unfixed, complete with influencing factors, in another section. Thus, they have kept both types of information (assimilation scenario) and have used them as they are presented—a behaviour that is common particularly in an educational system built on the memorisation of textbook content.

As shown in Table 5.2, multiple attempts were made in the workshop, combined with numerous explanations and examples, video analyses and graph reading, to help the teachers learn more about changes in state, the freezing and melting points of water and the heat of fusion. These explanations and examples were also intended to help them drive conceptual change for several misconceived concepts that were identified as mostly false beliefs schemas. Some of these false beliefs are as follows: ‘Heat and temperature are the same thing’; ‘Ice is at 0°C and/or cannot change temperature’; ‘objects of different temperature that are in contact with each other, or in contact with air at different temperature, do not necessarily move towards the same temperature’; ‘heat is proportional to temperature’; ‘a cold body contains no heat’; and ‘water cannot be at 0°C’.

The structure of all the activities and instruction was meant to help change the teachers’ old schemas and correspondingly aid their students’ understanding so they can correctly answer the TCE instrument questions (i.e. questions 1–3, 7, 9, 11, 15, 18, 20 and 24). The aforementioned concepts were recited verbally by the participating teachers but changes to the way the information is presented caused them to struggle. The teachers appeared to commit such concepts to memory as unconnected segments instead of interpreting them as a cause-and-effect series of interactions; this behaviour is attributed to the contradictions found in educational materials and language barriers. Vernacular language, for example, shows that Saudi people believe the temperature of ice to be the lowest temperature that a substance can reach. The phrase ‘colder than ice’ in the language means nothing can be found below the temperature of ice.

Several attempts during the Workshop were made to help the teachers modify ‘ice is at 0°C and/or cannot change temperature’ to a new schema (Table 6.13).

Table 6.13 *Attempts to change teachers' old schemas about freezing and melting point*

To-be-learned concept (new schema)	To-be-changed concept (old schema)			
Ice is at 0°C during changing states (i.e. liquid ↔ solid). Otherwise, it changes temperature.	Ice is at 0°C and/or cannot change temperature.			
1st attempt: What is the most likely temperature inside a fridge and inside the freezer section? [words cloud]	Teachers' frequent answers %			
	Fridge	%	Freezer	%
	3-7°C	57%	–3 to -4°C	57%
	0°C	43%	0°C	43%
2nd attempt: The temperature reading inside the freezer section was –18°C. What does that mean? [open-ended]	Teachers' frequent answers %			
	Means it's below the freezing point			43%
	No answer			43%
	Means it's has less thermal energy			14%
3rd attempt: [Video] At 5:55, he said the water temperature was –4°C of the mixture (water + ice). How could be that? (Periodic Videos, 2013)				

The first attempt to challenge their thinking, to predict what the teachers know about the temperature inside a refrigerator and its freezer section. The teachers' answers regarding refrigerator temperature ranged from 0°C to 7°C, and their predictions of freezer temperature ranged from 0°C to –4°C. Teachers' answers regarding the refrigerator temperature 0°C (≈43%) means that they are not fully comprehend the meaning of the freezing point. As well as teachers' who choose 0°C (≈43%) as an answer for the freezer temperature means that they are not fully comprehend the meaning of the melting point. It seems that teachers believe that–4°C (≈57%) is the lowest temperature the refrigerator's freezer compartment can reached. It was assumed that showing and discussing a video of a refrigerator equipped with a digital thermostat that reads the temperature of the refrigerator and freezer sections (i.e. 5°C to –18°C) will enable the teachers to change their old schema about ice reaching only a temperature of 0°C into ice could reaching lower temperatures. However, in the second attempt, 43% of teachers showed no response, and 57% showed no understanding what the –18°C inside the freezer means.

6.5.3 *Teachers' Misconceptions as Category Mistakes Schemas*

Some of the old schemas, such as 'materials like wool have the ability to warm things up' (Yeo & Zadnik, 2001, p. 498), are classified as *Category mistakes schemas* that require more than explicit or implicit refutation to correct. In the first attempt, conceptual change was triggered by asking the teachers if covering a thermometer with heavy cloth will change its reading. As responses to the questions in Table 6.14, 70% of the teachers guessed that the reading will change (increase /decrease).

Table 6.14 *An example of category mistakes schema: Intended and accommodated concepts.*

To-be-learned concept (new schema)	To-be-changed concept (old schema)	
Artefacts and living beings are different categories. Artefacts don't warm things up.	Materials like wool do not have the ability to warm things up.	
1st attempt: What will happen to a thermometer if we cover it with heavy wool cloth? (Annenberg Learner, 2004)	Teachers' frequent answers %	
	Will change %	70%
	No change %	30%
2nd attempt: What is the doll's temperature?	Teachers' frequent answers %	
	Same as a human's temperature	73%
	Not same	27%

In the second attempt, the teachers were asked to guess a doll's temperature. More than 73% of them stated that the temperature will be the same as a human's temperature. Further discussion was devoted to teach this concept to help the teachers assist their students in understanding the concept sometime during instruction with the thermal properties of materials. The effectiveness of the instruction can be reflected by the students' performance in the TCE instrument, especially in answering the questions related to this particular concept (e.g. Questions 14, 16, 17, 23 and 26). The percentage of the Pre and Post of Some of the Saudi Students misconceptions' (Old Schemas) as Mental Models are illustrated in Table 6.15.

Table 6.15 *The Percentage of the Pre and Post of Some of the Saudi Students Misconceptions' (Old Schemas) as Mental Models*

Misconceptions	TCE			Misconceptions %		Schema
	Question	Pre	Post	Pre	Post	
Heat is a substance	Q22. When Zack uses a bicycle pump to pump up his bike tires, he notices that the pump becomes quite hot. Which explanation below seems to be the best one?	c. Heat flows from his hands to the pump	b. Temperature has been transferred to the pump.	26%	24%	CM
Heat is proportional to temperature	Q7. Lee takes two cups of water at 40°C and mixes them with one cup of water at 10°C. What is the most likely temperature of the mixture?	d. 50°C	d. 50°C	24%	22%	FB
Heat and cold are different	Q10. Ned picks up the cola can and then tells everyone that the countertop underneath it feels colder than the rest of the counter.	a. Jon says: "The cold has been transferred from the cola to the counter."	a. Jon says: "The cold has been transferred from the cola to the counter."	39%	32%	CM
Heat and temperature are the same thing	Q15. A group is listening to the weather forecast on a radio. They hear: '… tonight it will be a chilly 5°C, colder than the 10°C it was last night'.	d. Guy says: "It's partly right, but she should have said that 5° C is half as cold as 10°C."	a. Jen says: "That means it will be twice as cold tonight as it was last night."	33%	21%	FB
The boiling point of water is 100°C (only).	Q8. Jim believes he must use boiling water to make a cup of tea. He tells his friends: 'I couldn't make tea if I was camping on a high mountain because water doesn't boil at high altitudes'.	c. Lou says: "The boiling point of the water decreases, but the water itself is still at 100 degrees."	c. Lou says: "The boiling point of the water decreases, but the water itself is still at 100 degrees."	41%	37%	FB
Boiling point is the maximum temperature a substance can reach.	Q19. Ron reckons his mother cooks soup in a pressure cooker because it cooks faster	b. Col says: "It's because the high	b. Col says: "It's because the high	47%	41%	FB

Misconceptions	TCE			Misconceptions %		Schema
	Question	Pre	Post	Pre	Post	
	than in a normal saucepan but he doesn't know why.	pressure generates extra heat."	pressure generates extra heat."			
The temperature of an object depends on its size.	Q14.Jan announces that she does not like sitting on the metal chairs in the room because 'they are colder than the plastic ones'.	d. Mai says: "They are colder because metal has less heat to lose than plastic."	a. Jim agrees and says: "They are colder because metal is naturally colder than plastic."	55%	35%	FB
Heating always results in an increase in temperature.	Q5. Five minutes later, the water in the kettle is still boiling. The most likely temperature of the water now is about:	c. 110°C	c. 110°C	38%	28%	FB
Temperature can be transferred.	Q13. After cooking some eggs in the boiling water, Mel cools the eggs by putting them into a bowl of cold water. Which of the following explains the cooling process?	a.Temperature is transferred from the eggs to the water.	d.Energy is transferred from the eggs to the water.	49%	44%	FB
Heat and cold flow like liquids	Q10. A few minutes later, Ned picks up the cola can and then tells everyone that the countertop underneath it feels colder than the rest of the counter.	a. Jon says: "The cold has been transferred from the cola to the counter."	a. Jon says: "The cold has been transferred from the cola to the counter."	39%	32%	CM
Heat flows more slowly through conductors making them feel hot	Q25. Gay is describing a TV segment she saw the night before: "I saw physicists make super-conductor magnets, which were at a temperature of –260°C."	d. Gay is not sure: "I think super-conductors are good heat conductors so you can't cool them to such a low temperature."	b. Kay disagrees: "Yes you can. There's no limit on the lowest temperature."	33%	27%	CM

Misconceptions	TCE			Misconceptions %		Schema
	Question	Pre	Post	Pre	Post	
Ice is at 0°C and/or cannot change temperature.	Q1. What is the most likely temperature of ice cubes stored in a refrigerator's freezer compartment?	B. 0°C		59%	54%	FB
Water cannot be at 0°C.	Q11. Pam asks one group of friends: 'If I put 100 grams of ice at 0°C and 100 grams of water at 0°C into a freezer, which one will eventually lose the greatest amount of heat'?	e. Jed says: "There's no answer, because you can't get water at 0°C."	e. Jed says: "There's no answer, because you can't get water at 0°C."	35%	26%	FB
Some materials are difficult to heat; they are more resistant to heating.	Q26. Four students were discussing things they did as kids. The following conversation was heard: Ami: 'I used to wrap my dolls in blankets but could never understand why they didn't warm up'.	c. Jay replied: "It's because the dolls were made of material which did not hold heat well."	c. Jay replied: "It's because the dolls were made of material which did not hold heat well."	51%	36%	CM
The bubbles in boiling water contain 'air', 'oxygen' or 'nothing'.	Q12. Mel is boiling water in a saucepan on the stovetop. What do you think is in the bubbles that form in the boiling water?	b. Oxygen and hydrogen gas	b. Oxygen and hydrogen gas	37%	34%	FB
Steam is more than 100°C.	Q6. What do you think is the temperature of the steam above the boiling water in the kettle?	d. 120 °C	d. 120 °C	42%	38%	FB
The boiling point of water is 100°C (only).	Q4. On the stove is a kettle full of water. The water has started to boil rapidly. The most likely temperature of the water is about:	d. None of the above answers could be right	d. None of the above answers could be right	55%	42%	FB
Materials like wool have the ability to warm things up.	Q17. Amy took two glass bottles containing water at 20°C and wrapped them in washcloths. One of the washcloths was wet and the other was dry. 20 minutes	c. 20°C	c. 20°C	40%	28%	CM

Misconceptions	TCE	Misconceptions %				Schema
	Question	Pre	Post	Pre	Post	
	later, she measured the water temperature in each. The water in the bottle with the wet washcloth was 18°C, the water in the bottle with the dry washcloth was 22°C. The most likely room temperature during this experiment was:					
The bubbles in boiling water contain "air," "oxygen," or "nothing."	Q12. Mel is boiling water in a saucepan on the stovetop. What do you think is in the bubbles that form in the boiling water? Mostly.	b. Oxygen and hydrogen gas	b. Oxygen and hydrogen gas	37%	34%	FB
Bubbles mean boiling	Q8. Jim believes he must use boiling water to make a cup of tea. He tells his friends: "I couldn't make tea if I was camping on a high mountain because water doesn't boil at high altitudes."	c. Lou says: "The boiling point of the water decreases, but the water itself is still at 100 degrees."	c. Lou says: "The boiling point of the water decreases, but the water itself is still at 100 degrees."	41%	37%	FB

Note. CM= Category Mistakes, FB= False Beliefs

6.6 Summary

Students' data derived from the TCE instrument and teachers' data from the focus group and interviews following the Science Teachers' Professional Development Workshop were analysed to answer Research Questions 1, 2, and 3, which are associated with students' and teachers' conceptual understating of thermal energy and their misconceptions. Descriptive and qualitative analyses were carried out to explore the students' beliefs before and after instruction. The results of the TCE post-test indicated that students achieved minimal improvement in terms of schema modification. The same holds true for the teachers despite all the attempts at helping them alter their old schemas. This deficiency was equally reflected in their students' achievements in the test. The obstacles to conceptual change approach amongst the participants would appear to be language barriers and ontological thinking. To conclude, Saudi female high school students' and their teachers' level of understanding of thermal concepts appears to be low. To this end, investigating possible sources of Saudi students' misconceptions regarding thermal energy is essential.

CHAPTER 7
POSSIBLE SOURCES' OF SAUDI STUDENTS' MISCONCEPTIONS ON THERMAL ENERGY

7.1 Introduction

The importance of the conceptual change approach is that it can help provide researchers with the information necessary to understand how students construct their knowledge, the ways these constructions change when they encounter new to-be-learned science concepts, and what difficulties they may come across during the process (Vosniadou, 2013). These difficulties may vary from one individual and one culture to another. To examine whether the thermal concepts are conceptually understood or not by Saudi students and their teachers, the TCE instrument has been used. As mentioned, the previous chapter centred on responses to Research Questions 1, 2, and 3 by explaining the difficulties Saudi female high school students and their female teachers encounter when processing conceptual changes in thermal physics misconceptions that have roots in the ontology tree. Similarly, this chapter revolves around Research Question 4—What are the possible sources of Saudi female high school students' misconceptions regarding thermal physics?—by elaborating on how the Saudi physics textbook and terminology promote, develop, and reinforce thermal physics misconceptions amongst Saudi female high school students and their teachers that may hinder them in processing conceptual change.

In this chapter, the Year 11 Saudi physics textbook that is referred to is the material written by Zitzewitz (2008) and published by Obeikan. The English version of the physics textbook is that written by Zitzewitz (2005) and published by Glencoe/McGraw-Hill. All misconceptions and the TCE were quoted and obtained from Yeo and Zadnik (2001) and taken verbatim from sources.

The chapter is structured as follows: Section 7.2 presents the exploration of Research Question 4 through a review of the Saudi physics textbook (Section 7.2.1), language and terminology issues (Section 7.2.2), and teachers' practical knowledge (Section 7.2.3). Each section provides numerous examples of how these three sources may have promoted erroneous responses in the TCE.

7.2 Research Question 4

What are the possible sources of Saudi female high school students' misconceptions regarding thermal physics?

As previously stated, the difficulties that students encounter may stem from the language barriers discussed in Chapter 5 and the science content that is written to satisfy American standards and translated into Arabic by the publisher Al-Obeikan (Alghamdi & Al-Salouli, 2013) with no attention paid to the relevance of such content to the Saudi environment and Saudi people's needs (Albadi et al., 2018). Problems in the Saudi physics textbook content have been identified by a number of researchers. Albadi et al. (2018), for example, found that in a cloze test, Saudi students were able to fill in only one-third of the missing scientific words in a paragraph that contains 50 words, and only 28% of the concepts were conceptually understood in the correct manner by the students. The authors concluded that the language in the examined Year 10 physics textbook exhibits potential problems associated with readability and that students' low achievement is due to 'text accessibility rather than learner competence' (p. 649). The content is made more difficult by the presentation of mathematical concepts in the textbook, considering that the Saudi students lack basic mathematics skills, such as addition, subtraction, multiplication and division (Albadi et al., 2018). In this study, the examined terminologies in conjunction with unreliable translations may explain why conceptual change does not occur among Saudi students. In addition, this study revealed that Saudi physics textbooks frequently promote *false beliefs* schemas and reinforce advanced misconceptions, such as *category mistakes* schemas. Table 7.1 illustrates two examples of reviewed statements found in the English version of the Year 11 Saudi physics textbook, and in Yeo and Zadnik (2001) are identified as misconceptions.

Table 7.1 *Two statements in the Saudi textbook with almost the same misconceptions as those found in Yeo and Zadnik (2001) list*

Saudi Physics textbook	Page	Yeo and Zadnik (2001)	Page
Some objects are easier to heat than others.	317	Some materials are difficult to heat.	498
The increase in temperature depends on the size of the object.	317	The temperature of an object depends on its size.	498

Note: All textbook statements in Tables were taken verbatim from sources.

In what follows, a detailed review of the Year 11 Saudi high school physics textbook and its terminologies is provided, along with a discussion of the material's contribution to the proliferation and reinforcement of different levels of misconceptions list (false beliefs schemas, category mistakes schemas, etc.) that originate from language ambiguity or misleading/unreliable translations.

7.2.1 Review of the Year 11 Saudi High School Physics Textbook

Examples of Misconceptions Promoted by the Book

The Arabic version of *Physics Principles and Problems 2005,* jointly published by Glencoe/McGraw-Hill and Obeikan, was evaluated. This textbook is used as the official and mandatory material for Year 11 students studying in government-funded Saudi schools (Albadi, Harkins, & O'Toole, 2017). The original textbook (i.e. the

Zitzewitz (2005) version) consists of 958 pages, which, in the Arabic version, are divided into four sections, namely, Physics 1 to Physics 4; each book section is studied at any semester during Years 10 to 12; thermal concepts are in Physics 3. The Arabic version does not feature content adjustments that are aimed at correspondence with the Saudi context, but some images were modified to match Saudi culture (e.g. images of females were replaced with those of males).

Example 1: 'Heat flows more slowly through conductors'.

The lack of content adjustment in the information found in the Saudi physics textbook may promote false beliefs schemas among Saudi students regarding thermal concepts. To illustrate, because the Eastern Province of Saudi Arabia has an almost fully dry climate, the average temperature in the area falls between 45°C and 54°C, and the temperature along roads reaches 72°C in the summer in some area of the country, which lasts for almost nine months (Ramadhan & Wahhab, 1997). Figure 7.1 illustrate the introductory experiment in the thermal energy chapter (i.e. Chapter 12 in the English version and Chapter 5 in the Arabic version) is meant to capture students' attention and inspire curiosity, but it involves the exposure of water to a minimal amount of heat.

What happens to the temperature of water
when you hold a glass of water in your hand?

Figure 7.1 Source: Zitzewitz (2005, p. 313)

Understanding is unlikely because most of Saudi Arabia experiences nearly year-round severely hot temperatures, at which water may begin boiling. Thus, the application of minimal heat will not result in a noticeable effect and cause failure in the experiment. Accordingly, students may form faulty judgments and end with unjustifiable conclusions due to lack of available evidence (Posner et al., 1982). At the same time, teachers may be unaware of what caused the failure of the experiment or what may have gone wrong during the activity.

For conceptual change to occur, students' satisfaction with an intended concept and dissatisfaction with an old schema must be at their highest levels (Duit et al., 2008); these can be achieved when the intended concept is more intelligible, plausible and fruitful than the old schema (Posner et al., 1982). The example discussed above does not exhibit these three qualities. With content that fails to satisfy students' needs or consider the context specific to learners, students will experience difficulties in processing scientific information and thus become vulnerable to the formation of more easily processed misconceptions. This example of unadjusted information may explain why students may not notice the difference in water temperature when they touch it, thus it may lead students to form erroneous inferences, such as this one listed by Yeo and Zadnik (2001, p. 498): 'Heat flows more slowly through conductors'. One of the adjustments that should be applied in this regard is, at the least, a caveat or a note addressed to Saudi teachers that for some contents experiment designs and other textbook components need amendments to reflect activities that correspond with the severe climate in Saudi Arabia. Such amendments could limit the factors that cause experiment failure.

Example 2: 'Objects of different temperature that are in contact with each other … do not necessarily move toward the same temperature [thermal equilibrium]'

Conceptual change is also advanced by clear 'communication' between users and a source; this idea was referred to as the knowledgeability of students regarding old schemas and new ones in the study of Chi (2013) and as the intelligibility of new schemas in Posner et al. (1982) research. The ambiguity of content translation may drive students to comprehend a concept in a manner that contradicts the intended understanding, thereby giving way to the development of faulty predictions and unjustifiable conclusions. This ambiguity was one of the most frequently noticeable errors in the review of the Saudi physics textbook. For instance, the assumption held by many Saudi teachers of every discipline is that room temperature is fixed at 20°C; they refer to this temperature as ‘standard room temperature’. In Saudi teachers’ points of view, the word ‘standard’ mostly means *scientific* and is unrelated to students’ daily lives; its use is therefore restricted to educational purposes in schools. The point of room temperature was later changed to 25°C, but some reference writers still struggle with this value, thus driving the definition of this temperature as ranging from 20°C to 25°C.

A quick scan of Platform.almanhal.com (2017), which is an academic publisher’s platform published in English, revealed that numerous advanced studies published in Saudi Arabia and other Arabian countries refer to this range as reflecting room temperature. This makes room temperature another point that Saudi students believe to be fixed; the other two are the boiling and freezing points (Chapter 6, Section 6.4). This information is mentioned even in university-level Saudi physics textbooks. Similar information was found in English versions of these textbooks or books such as Giancoli (2005), which is used in Saudi universities. The logic of the context may mean that all measurements and experiments in physics (and other fields) are measured at a room temperature of 20°C. Adopting different room temperatures yields different results; thus, obtaining the same results presented in the English textbooks requires manipulating the room temperature in Saudi textbooks so that it is identical to the room temperature featured in the measurements or experiments in the English materials. In the workshop and focus group discussion, these Saudi teachers were informed that the standard figures were measured and defined at a certain temperature and atmospheric pressure so that they would know of the purpose of using them as a fundamental reference. However, these teachers also learned by experience that they must use these standard figures as part of the scientific content of a textbook that was translated from a source for them to derive the same problems' answers provided in the teacher's guide book as reported by Albadi et al. (2018), Qablan et al. (2015), and Zabihi and Tabataba'ian (2011), regardless of the actual reading of the surrounding temperature and atmospheric pressure.

This illogical assumption, which can be defined as a false belief schema, is driven by the ambiguity of language translation; combined with the lack of training among teachers, it has resulted in the embedding of the assumption in the minds of students and teachers since the early stages of Saudi female education 60 years ago.

Table **7.2**, which provides some details regarding the original Saudi physics textbook (English version), indicates that the phrase 'room temperature' appears 31 times, with most of them referring to 20°C as the room temperature and one identifying 21°C as the room temperature. This assumption may be responsible for the lack of understanding regarding the mechanism of thermal equilibrium; it has also promoted many of the false beliefs schemas listed in Yeo and Zadnik (2001), such as 'objects of different temperature that are in contact with each other, or in contact with air at different temperature, do not necessarily move toward the same temperature' (see Yeo & Zadnik, 2001, p. 498).

Table 7.2 *Students and teachers' answers regarding room temperature*

	Phrase	Repeat	Location in textbook	Page
Saudi textbook	Cup is 20.0°C at room temperature.	1	Problems	336
	From room temperature (20.0°C)	1	Problems	337
	At room temperature, 21°C	1	Problems	362
	At room temperature (20°C)	1	In text	404
	Normal room temperature, which is 20°C	1	Problems	416
	At room temperature (20°C)	1	In text	423
AC	'Objects of different temperature that are in contact with each other … do not necessarily move toward the same temperature'			
TCE	Q17. Amy took two glass bottles containing water at 20°C and wrapped them in washcloths. One of the washcloths was wet and the other was dry. 20 minutes later, she measured the water temperature in each. The water in the bottle with the wet washcloth was 18°C, the water in the bottle with the dry washcloth was 22°C. The most likely room temperature during this experiment was: a. 26°C b. 21°C c. 20°C d. 18°C			

Q17 incorrect answers' %	Pilot study	Pre-test	Post-test
Option (c): 20°C	50%	40%	28%

Note: All textbook statements in Tables were taken verbatim from sources.

Students who believe that room temperature is fixed at 20°C may generate incorrect predictions and illogical explanations and thereby draw faulty conclusions, as evidenced in their responses to the questions in the TCE. An example is the response to Q17 of the test, which asks students to identify room temperature. At first glance and without carrying out calculations, students are likely to choose 20°C as their response, no matter the additional information provided in the question. The proportions of students who selected 20°C as their response in the pilot study, the pre-TCE and the post-TCE are relatively high. Among the pilot study population, 50% stated that room temperature is 20°C. In the pre-test (administered before instruction on thermal energy), 40% of the students also indicated that room temperature is equal to 20°C. This proportion decreased to 28% in the post-test (administered after a few weeks of instruction on thermal energy).

Yet another source of confusion among teachers and students regarding thermal equilibrium appears in the Saudi physics textbook. Table 7.3 presents a statement from the Saudi physics textbook that reads ‘when two objects come in contact with each other, they transfer energy’ (p.317). This statement indicates that any two objects that come into contact will exchange energy, which contradicts the thermal equilibrium rule that point out that heat flows between two objects ‘only’ if they have unequal thermal energy (e.g. one object has a higher temperature than the other). Table 6.10 shows that thermal equilibrium is accorded eight questions in the TCE (i.e. Q1, Q2, Q3, Q6, Q9, Q10, Q17 and Q24).

Table 7.3 *Confusion over thermal equilibrium as listed in Saudi textbook and the percentage of students got misconceptions regarding thermal equilibrium.*

Saudi textbook				Misconceptions				
‘When two objects come in contact with each other, they transfer energy’ (p. 317)				‘Objects of different temperature that are in contact with each other … do not necessarily move toward the same temperature’ (p.498)				
TCE	Q1	Q2	Q3	Q6	Q9	Q10	Q17	Q24
Pre	73%	87%	74%	83%	83%	66%	74%	87%
Post	72%	78%	80%	83%	82%	69%	73%	82%

Note: All textbook statements in Tables were taken verbatim from sources.

This statement, and some others, may foster flawed thermal equilibrium knowledge that leads to unjustifiable conclusions, such as ‘objects of different temperature that are in contact with each other, or in contact with air at different temperature, do not necessarily move toward the same temperature’ (Yeo & Zadnik, 2001, p. 498). The information deficiencies in the Saudi physics textbook may have affected the students' answers to these questions.

Example 3: 'Heat and temperature are the same thing'

The term 'temperature' does not exist in the Arabic language, unlike many other languages as investigated by Wiser and Carey (2014), thus easily causing confusion between heat and temperature, even among high-level educators. The term closest to 'temperature' in the Vernacular Arabic language is 'heat intensity'. In the same time, 'temperature' translated into 'heat degree' in Modern Standard Arabic, which makes it an *unfortunate* term because the phrase 'heat degree' points to how hot an object is and not to the *speed* of molecules. In the same time, 'Heat intensity' (i.e. old concept) is used in vernacular language, whereas 'Heat degree' (i.e. new concept) which attached to the Modern Standard Arabic language is limited to use in schools due to the fact that using the Modern Standard Arabic language in schools is compulsory by the government (Fatimah Alninya, personal communication, May, 2015). The latter appears to have failed to stimulate satisfaction among the students, thus resulting in infrequent usage. Both terms have generated insufficient satisfaction and thus move towards the equilibrium level in the satisfaction matrix (see Table 4.1). Thus, students use the two terms alternately depending on context. This study reveals that heat and temperature are used interchangeably in the Saudi physics textbook as illustrated in Table 7.4.

Table 7.4 *Interchange between heat and temperature, and percentage of students who believed on the related misconceptions MCs*

Topic	English version	Page	Arabic version	Page	Meaning in Arabic
Thermal energy	You will learn how temperature relates to the potential and kinetic energies of atoms and molecules.	312	تعرف العلاقة بين الحرارة وطاقتي الوضع والحركة للذرات والجزيئات	134	You will know about the relationship between heat and the potential and kinetic energies of atoms and molecules.
States of matter	Great differences in pressure and temperature	340	الاختلافات الهائلة في الضغط و الحرارة	170	Great differences in pressure and heat
Gas laws	Pressure, temperature, and volume	344	الضغط ، والحرارة ، و الحجم	176	Pressure, heat and volume
Solids	The importance of thermal expansion	359	توضح أهمية تمدد المواد بالحرارة	196	The importance of material expansion with heat
Thermal expansion	That expands with temperature	363	يتمدد بازدياد الحرارة	201	That expands with increasing heat
MC	Heat and temperature are the same thing				
TCE	Q15. A group is listening to the weather forecast on a radio. They hear: '… tonight it will be a chilly 5°C, colder than the 10°C it was last night'. a. Jen says: "That means it will be twice as cold tonight as it was last night." b. Ali says: "That's not right. 5° C is not twice as cold as 10°C." c. Raj says: "It's partly right, but she should have said that 10° C is twice as warm as 5°C." d. Guy says: "It's partly right, but she should have said that 5° C is half as cold as 10°C."				

Q15 incorrect answers' %	Pilot study	Pre-test	Post-test
Option a+b+c	76%	85%	75%

Note: All textbook statements in Tables were taken verbatim from sources.

In the Obeikan Saudi physics textbook, the word ‘temperature’ found in the McGraw-Hill English version[10] is translated into ‘heat’ multiple times. At the same time, ‘thermometer’ is translated into ‘heat scale’ in almost every single Arabic material and dictionary. In addition, ‘body temperature’ is translated into ‘body heat degree’ in the Arabic version of the McGraw-Hill physics textbook (p. 146 of the textbook). This reflected in the percentage of students who chose option a, c and d as their answer to question 15 of TCE. Those incorrect answers options are associated with several misconceptions such as ‘Heat and temperature are the same thing’ (see Table 7.4); ‘Temperature is the “intensity” of heat’ (see Table 7.5) and ‘Heat is proportional to temperature’ (see Table 7.6).

In the Saudi physics textbook alone, which reproduces only 234 pages out of the original 958, ‘heat scale’ appears 25 times compared with ‘heat degree scale’, which is mentioned only twice. This treatment leaves the impression that ‘heat degree’ means ‘temperature’ in Arabic. This interchanging between the two terms confounds teachers’ and students’ understanding of the two concepts and related information, such as gas laws, wherein ‘temperature’ is translated into ‘heat’, as listed in page 344 of the English version. The challenging problem regarding thermal expansion in page 363 of the original material becomes more challenging as ‘temperature’ is again translated into ‘heat’. Under ‘applications of thermal expansion’, the translator of the Saudi physics textbook added three extra lines (p. 202) that are not found in the source and features the same heat/temperature translation error. The concepts of heat flow and heat transfer are treated as synonymous in the Arabic version, and ‘thermostat’ is translated into ‘heat regulator’.

[10] The McGraw-Hill Company is the provider of all Saudi science textbooks from K–12 and the university level. The Obeikan Company acquired the rights for translating all these textbooks.

This is not the only instance where translation mistakes occur. Similar errors can be found in the *Physics 4* textbook that was used as an official national textbook for Year 11 from 2005 to 2011 and taught to hundreds of thousands of students around the kingdom. It was prepared and edited by Saudi authors, who apparently have little knowledge of the English language, attempted to provide English titles to each lesson but these failed in these translations. For example, the authors erroneously translated 'convection' into 'heat transfer pregnancy' and classified it into 'normal pregnancy' and 'forced pregnancy'—errors that are repeated throughout the text (see Appendix H). These errors give rise to concerns over the professionalism that these experts exhibit and the manner by which they translate works; this lack of competence affects the overall accuracy of many Saudi science textbooks.

As can be seen, Saudi Physics textbooks would appears to have contributed to the confusion of students and the proliferation of misconceptions, such as 'heat and temperature are the same thing' as it showed in Yeo and Zadnik (2001, p. 498). Given unreliable translations, along with language barriers, Saudi students' understanding of scientific concepts becomes considerably challenging, thus leaving no room for conceptual change to occur.

Example 4: 'Temperature is the "intensity" of heat'

Conceptual change among students necessitates awareness of their old invalid schemas and new valid schemas. Given the lack of unity and coherence in the Saudi physics textbook, teachers and their students involved in this study, seem to have a difficult time acquiring a unified comprehension of to-be-learned concepts that are presented in the textbook. An example of how confusion may arise from fragmented information is illustrated in Table 7.5. In this example which was carefully investigated among others, the information presented at the beginning of a lesson was in contrast to that presented at the end of the lesson, or information presented in between are mismatched. In other words, the conditions that enable students to build satisfaction with new scientific content are missing. In the absence of such conditions, conceptual change is likely to be unsuccessful, and the risk that students will develop new misconceptions is very high. As indicated in the results of the TCE (see Table 7.5), in Q15 the percentage of students who hold scientific conceptions was no more than 25% before and after the study of materials on thermal energy.

Table 7.5 *Percentage* of *students who believe on misconceptions as responses to question 15(option a,b,c combined).*

	Text	Page	Text	Page
Textbook*	You will learn how temperature relates to the potential and kinetic energies of atoms and molecules	312	Temperature depends only on the average kinetic energy of the particles in the object	315
MC	Temperature is the "intensity" of heat.			
TCE	Q15. A group is listening to the weather forecast on a radio. They hear: '… tonight it will be a chilly 5°C, colder than the 10°C it was last night'. a. Jen says: "That means it will be twice as cold tonight as it was last night." b. Ali says: "That's not right. 5° C is not twice as cold as 10°C." c. Raj says: "It's partly right, but she should have said that 10° C is twice as warm as 5°C." d. Guy says: "It's partly right, but she should have said that 5° C is half as cold as 10°C."			

Q15 incorrect answers %	Pilot study	Pre-test	Post-test
Option a+b+c	76%	85%	75%

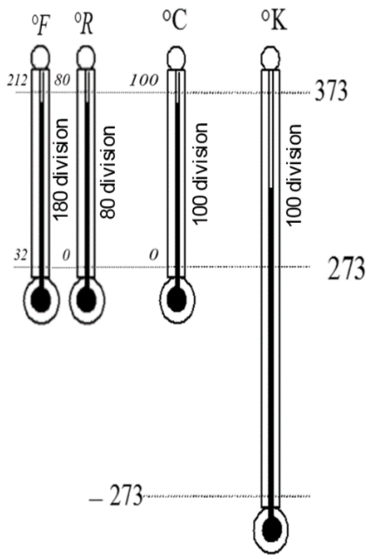
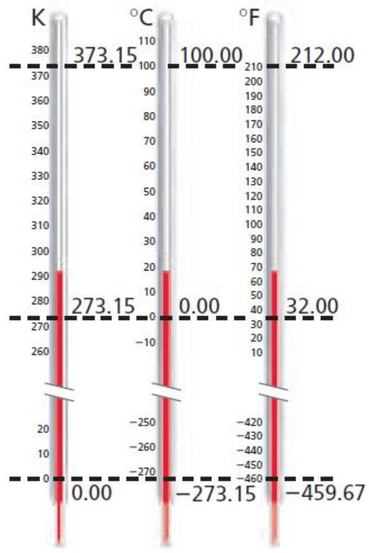
** Saudi physics textbook*
Note: All textbook statements in Tables were taken verbatim from sources.

In the example illustrated in Table 7.5, the statement on page 312 of the Saudi physics textbook that students will learn ‘how temperature relates to the potential and kinetic energies’(which is aa incorrect statement), but the sidebar regarding temperature on page 315 of the book indicates that ‘temperature’ depends only on average kinetic energy (which is a correct statement). Such a mixture of both unreliable and inaccurate statements may prevent Saudi physics teachers and their students from easily determining that temperature depends on the speed with which molecules move (Molecular Kinetic Energy) and advance the development of false beliefs schemes, such as the ones listed by Yeo and Zadnik (2001, p. 498). For instance, this misconception ‘heat and temperature are the same thing’ is believed by 85% of the Saudi students responded to TCE (see Table 7.4 and Table 7.5).

Example 5: ‘Heat is proportional to temperature’.

To promote successful conceptual change among students, the information that they receive must be characterised by unity and sequence that reinforce their understanding of scientific knowledge and increase their awareness of concepts that align and do not align with modern scientific content (Chi, 2013). Evidence showed that the sequence of concepts in the newer Saudi physics textbook has been changed without informing teachers (Albadi et al., 2018), thereby leaving Saudi students with insufficient information regarding fundamental scientific concepts—a deficiency that can be attributed mainly to poor translation from the source. For instance, for decades, Saudi high school physics textbooks featured comparisons of temperatures at four scales (left-side Figure, Table 7.6).

Table 7.6 *Misleading Figures in the Saudi physics textbook and students' responses to the related TCE question*

	Old Scales (A)*	New Scales (B)**
Temperature scales comparison		
MC	Heat is proportional to temperature.	
TCE	Q15. A group is listening to the weather forecast on a radio. They hear: '… tonight it will be a chilly 5°C, colder than the 10°C it was last night'. a. Jen says: "That means it will be twice as cold tonight as it was last night." b. Ali says: "That's not right. 5° C is not twice as cold as 10°C." c. Raj says: "It's partly right, but she should have said that 10° C is twice as warm as 5°C." d. Guy says: "It's partly right, but she should have said that 5° C is half as cold as 10°C."	

Q15 incorrect answers %	Pilot study	Pre-test	Post-test
Option a+b+c	76%	85%	75%

Note: All textbook statements in Tables were taken verbatim from sources.
** Source: Internet   ** Source: (Zitzewitz, 2005, p. 316)*

An item found in the new edition of the McGraw-Hill textbook was translated into Arabic, but the Figure was also modified (right-side Figure, Table 7.6). Saudi teachers frequently encounter the representation on the left-side Figure in Table 7.6 in nearly every material that they refer to. The teachers experience difficulties in adjusting their orientation to match the temperature scale represented in the right-side Figure in Table 7.6.

As might be expected, the Saudi teachers continually claim that it is excessively easy for students to understand and draw the thermometer diagram shown on the left side but Saudi teachers and students who continue to use this left side Figure will fail to determine that 10°C is not the doubled measurement of 5°C in the TCE. This evaluation is clearly supported by the students' responses to Q15 of the TCE.

Example 6: 'Ice is at 0°C and/or cannot change temperature'

One of the false beliefs schemas that Saudi students developed from their vernacular language is the idea that ice is the ultimate coldest object. For instance, this study found that almost all the teachers who participated in The Professional Development Workshop do not know exactly what temperature to expect in a refrigerator or freezer. Their students therefore experienced difficulty in answering related TCE questions, such as Q1 (see Table 7.7), to which 73% responded that 'ice is at 0°C and/or cannot change temperature'(Yeo & Zadnik, 2001, p. 498). Carrying this idea in their minds, students encounter difficulties in their attempts to formulate predictions, explanations and conclusions about the everyday phenomena that they encounter. This problem is exacerbated with the proliferation of such false beliefs schemas in the Saudi physics textbook. For instance, the terms 'freezer' and 'freezer compartment' or any label that approximates these do not appear anywhere in the entire McGraw-Hill version. This means that high school students will never obtain information about the temperature inside the refrigerator's freezer compartment throughout their education. So, the information students learn is accidently from non-reliable sources (i.e. newspaper). This tendency is reflected in the students' choices options in the questions.

Table 7.7 *Repetition of 'freeze' in the Saudi textbook and the percentage of students believe in option b (misconception)*

	Phrase	No. of repetitions
Saudi textbook	Freeze/s	4
	Freezing	14
	Freezer compartment	0
	Freezer	0
	Refrigerator	28
MC	Ice is at 0°C and/or cannot change temperature.	
TCE	Q1. What is the most likely temperature of ice cubes stored in a refrigerator's freezer compartment? a. –10°C b. 0°C c. 5°C d. It depends on the size of the ice cubes.	

Incorrect answers %	Pre-test	Post-test
Option (b): 0°C	73%	72%

Note: All textbook statements in Tables were taken verbatim from sources.

Example 7: 'A cold body contains no heat'

High school students are expected to develop their mathematical skills during this stage of their life (Savinainen & Scott, 2002) but hyperbolic statements in textbooks tend to complicate this process because such statements are often illogical. Students usually become highly anxious when they encounter many, and sometimes unnecessary, numerical items, numbers with decimal points and numerical data with power series. The questions in Table 7.8, for example, revolve around the masses of water temperature, which are listed as 2.00×10^2 g and 4.00×10^2 g. These statements would have made more sense had the measurements been written as 200g and 400g. The first measurement is equal to a 200 mL cup of water, and the second is equivalent to two cups of water.

Table 7.8 *Presentation in the Saudi physics textbook and TCE results*

	Example	Page
Saudi textbook	A 2.00×10^2-g sample of water at 80.0°C is mixed with 2.00×10^2 g of water at 10.0°C. Assume that there is no heat loss to the surroundings. What is the final temperature of the mixture?	(p. 321)
	A 4.00×10^2-g sample of methanol at 16.0°C is mixed with 4.00×10^2 g of water at 85.0°C. Assume that there is no heat loss to the surroundings. What is the final temperature of the mixture?	(p. 321)
MC	'A cold body contains no heat' (p.498).	
TCE	Q7. Lee takes two cups of water at 40°C and mixes them with one cup of water at 10°C. What is the most likely temperature of the mixture? a. 20°C b. 25°C c. 30°C d. 50°C	

Q7 incorrect answers %	Pre-test	Post-test
Option (a+b+d)	46%	51%

Note: All textbook statements in Tables were taken verbatim from sources.

Students who are not used to working with mathematical modules will have trouble linking what they study in school to everyday life events. Q7 in the TCE is similar to the problems shown in Table 7.8. The results showed that in the pre-test, 46% of the Saudi students expressed the belief that 'a cold body contains no heat'. This percentage increased to 51% after instruction, suggesting that Saudi students may have encountered difficulties converting mathematical Figures and numbers to the equivalents used in daily living.

Another complicating feature of the textbooks is the use of one or two decimal places in expressions of 0°C. In the McGraw-Hill physics textbook, the forms '0°C', '0.0°C', '0.00°C' and '0.000°C' appear 16, 16, 6 and 1 time, respectively (see Table 7.9). Such simple numerical changes may cause students to pause for a few seconds (maybe hours) to ask themselves what is happening or what has changed or why this certain changes occur in a particular page of the textbook and not others.

Table 7.9 *Frequencies of different forms occurrence of zero degrees in the Saudi textbook*

	0.000°C	0.00°C	0.0°C	0°C
Frequency	1	6	16	16

Example 8: 'Water cannot be at 0°C'

In the entire McGraw-Hill physics textbook, the phrase 'ice water' appears only once, suggesting that ice water is a rare phase of water. For example, the phrases where 0°C is expressed in relation to water appear twice, and the phrase 'water at 273 K' appears once. The few expressions regarding the possibility that water retains its liquid form at 0°C are insufficient for students to believe that this information is factual. Moreover, statements indicating that water can be found at this temperature appear six times in the problem-solving section, but such frequency does not guarantee that students will encounter the statements enough times for the information to be firmly embedded in their minds. This issue may have influenced student performance in the TCE, especially with respect to Q11. The percentages of students who chose correct and incorrect answers are listed in

Table **7.10**.

As reflected by the TCE pre-test results, 38% of the pilot study participants and 35% of the pre-test participants believe that water cannot be found at 0°C. Among the students, 21% answered Q11 correctly. In the post-test, 26% of the students erroneously shared the same thought, whereas 20% provided the correct answer.

Table 7.10 *'Water exists at 0°C' (Saudi textbook) and percentage of students who believe that water cannot be found at 0°C*

Topic	Phrase	Page
Heat of fusion	The ice becomes 1 kg of water at the same temperature, 273 k.	324
Melting	And add ice water to cup b	324
Heat of fusion	To become water at 0.0°C	325
Heat of fusion	Energy required to heat the 454 g of water from 0.00°C'	339
Thermal expansion	When water is heated from 0°C to 4°C	347
Forces within liquids	The unexpected behaviour of water between 0°C and 4°C	349
Thermal equilibrium	Sample of water at 0.0°C in a calorimeter	873

MC Water cannot be at 0°C

TCE Q11. Pam asks one group of friends: 'If I put 100 grams of ice at 0°C and 100 grams of water at 0°C into a freezer, which one will eventually lose the greatest amount of heat'?

a. Cat says: "The 100 grams of ice."
b. Ben says: "The 100 grams of water."
c. Nic says: "Neither because they both contain the same amount of heat."
d. Matt says: "There's no answer, because ice doesn't contain any heat."
e. Jed says: "There's no answer, because you can't get water at 0°C."

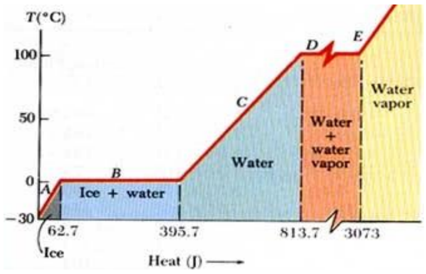
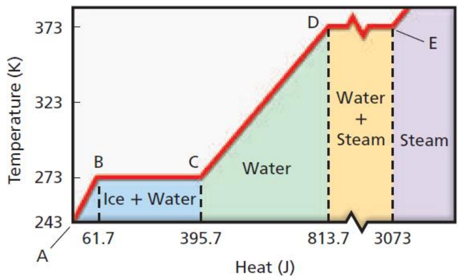
Incorrect answers %	Pilot study	Pre-test	Post-test
Option (e) %	38%	35%	26%

Note: All textbook statements in Tables were taken verbatim from sources.

Example 9: 'The boiling point of water is 100°C (only)'

As discussed in Chapter 6, section 6.4 the boiling point has been thought of for many decades as fixed at 100°C without any consideration to the atmospheric pressure (Teacher #6, personal communication, 2015). This false belief may have found supportive text in the Saudi physics textbook and thus enabled its proliferation among Saudi teachers and their students. Modern Standard Arabic uses the Celsius scale as a unit of temperature. In the new editions of the McGraw-Hill physics textbook (published from 2008 and after), the authors converted all the measurements in the globally used 'Changes of State' chart into Kelvin instead of Celsius (see Table 7.11).

Table 7.11 *A compression between the old information and the new information in Saudi textbook*

<table>
<tr><th></th><th>A*</th><th colspan="2">B**</th></tr>
<tr><td>Changes of state</td><td>
</td><td colspan="2">
</td></tr>
<tr><td>MC</td><td colspan="3">The boiling point of water is 100°C (only) (p.498).</td></tr>
<tr><td>TCE</td><td>Q4. On the stove is a kettle full of water. The water has started to boil rapidly. The most likely temperature of the water is about.
a. 88°C
b. 98°C
c. 110°C
d. None of the above answers could be right.</td><td>Q8. Jim believes he must use boiling water to make a cup of tea. He tells his friends: ‘I couldn’t make tea if I was camping on a high mountain because water doesn’t boil at high altitudes’.
a. Joy says: “Yes it does, but the boiling water is just not as hot as it is here.”
b. Tay says: “That’s not true. Water always boils at the same temperature.”
c. Lou says: “The boiling point of the water decreases, but the water itself is still at 100 degrees.”
d. Mai says: “I agree with Jim. The water never gets to its boiling point.”</td><td>Q19. Ron reckons his mother cooks soup in a pressure cooker because it cooks faster than in a normal saucepan but he doesn’t know why.
a. Emi says: “It’s because the pressure causes water to boil above 100°C.”
b. Col says: “It’s because the high pressure generates extra heat.”
c. Fay says: “It’s because the steam is at a higher temperature than the boiling soup.”
d. Tom says: “It’s because pressure cookers spread the heat more evenly through the food.”</td></tr>
<tr><td></td><td>Q4 option (d) %</td><td>Q8 option(b+c+d) %</td><td>Q19 option (b+c+d) %</td></tr>
<tr><td>Pre</td><td>55%</td><td>77%</td><td>90%</td></tr>
<tr><td>Post</td><td>42%</td><td>71%</td><td>83%</td></tr>
</table>

Note: All textbook statements in Tables were taken verbatim from sources.
** Source: Internet* *** Source: Zitzewitz (2005, p. 323)*

These changes have been done without giving a reason for the recent alterations. For instance, the boiling point 100°C now appears in the chart as 373 K. The same revision was applied to the freezing/melting point 0°C, which is now expressed in the chart as 273 K. Some related texts were modified accordingly, whereas others were not. In other cases, the two measurements—Celsius and Kelvin—are used on the same page (i.e. pp. 316 and 873). Table 7.11 illustrates these changes and TCE associated questions and students answers to those questions. To keep pace with these changes, all the new thermometers provided by the laboratory warehouse of the Saudi Ministry of Education were labelled in Kelvin instead of Celsius, as observed during the school visits. These modifications, however, were applied only to high school physics textbooks, indicating that before reaching the high school level, students use Celsius to express temperature and then shift to Kelvin once they commence their high school education.

For decades, the Saudi science curricula have lacked a logical scope and sequencing from one educational level to another as mentioned by Al-Ghanem (1999), which has denied students the know-how that they need to enhance their understanding of scientific concepts. Such knowledge may not be simultaneously offered in one Year level because of curricular deficiencies—a problem that can be attributed to poor curriculum design. Students require comprehensive instruction on abstract concepts for them to convert theoretical knowledge into practical (application) abilities. A well-designed curriculum is one that advances student understanding as they progress from one Year to another. This component guarantees that students obtain adequate instruction on thermal energy as they advance through Year levels. Students who are used to seeing the boiling point of water as 100°C are compelled to adjust to the new reading scale. These huge changes in measuring temperature have undoubtedly affected students' comprehension of scientific materials regarding thermal physics concepts, as asserted by Albadi et al. (2018).

With respect to measurements such as 0°C, 37°C and 100°C students can form a mental image of melting point, human body temperature and boiling point, respectively. The same representations are not as easy to recall when they are rendered in the Kelvin forms 273, 310 and 373 K. The results of the TCE showed that around 50% of the students believe that boiling point must be 100°C only (Q4), and up to 90% of them indicated that this temperature cannot be changed (Q8 and Q19). Teachers themselves are accustomed to the Celsius scale and are forced to adjust their decade-long orientation to keep in step with the new scale adopted in the textbook (Al-mofaker, 2009). This separation between what students use and learn at school (Kelvin) and what they use outside of school (Celsius) inspires compartmentalisation of knowledge, where the use of scientific information is restricted to school settings and 'does not have anything to do with real life' (Posner et al., 1982, p. 221). This separation may have created an environment for the enhancement, flourishing and carrying on of false beliefs schemas among students as it compels them to focus on memorising numbers and figures and pay little attention to conceptual understanding and solving problems.

Example 10: 'Steam is more than 100°C'

Despite the fact that the steam emanating from boiling water cannot have a temperature higher than that of the water, the McGraw-Hill physics textbook indicates that such steam can reach temperatures of 110°C, 120°C, 130°C and 140°C under normal atmospheric pressure. Without reference to the boiling point, this statement gives Saudi teachers and students the impression that the temperature of the steam arising from boiling water is higher than that of the water itself. This idea has been embedded in Saudi teachers' minds for decades (Teacher # 8 personal communication, 2015). Table 7.12 illustrates this issue of steam temperature which is associated with Q6 option c and d of TCE.

Table 7.12 *Steam temperature in Saudi physics textbook and students' responses to Q6 in the TCE*

	Phrase	No. of repetitions	Location in textbook	Page
Textbook	Steam at 110°C	1	Problems	331
	Steam at 120°C	1	Problems	337
	Steam at 130°C	1	Problems	325
	Steam at 140°C	1	Problems	325
MC	Steam is more than 100°C (p.498).			
TCE	Q6. What do you think is the temperature of the steam above the boiling water in the kettle? a. 88°C b. 98 °C c. 110 °C d. 120 °C			

Q6 incorrect answers' %	Pilot study	Pre-test	Post-test
Option (c) 110 °C	27%	25%	26%
Option (d) 120 °C	33%	41%	38%
Option (c+d)	60%	66%	64%

Note: All textbook statements in Tables were taken verbatim from sources.

Among the students, 25% and 26% stated that the temperature of steam is 110°C in the pre- and post-test, respectively, whereas 41% and 38% chose 120°C as their answers in the pre- and post-test, respectively. These results mean that 60% of the pilot study participants, 66% of the pre-test participants and 64% of the post-test participants believe steam temperature to be higher than boiling water temperature.

In short, due to lack of knowledge and skills, authors failed to choose the appropriate meaning in the Arabic language that matched the original meaning. Thus, the Saudi physics textbook has, over generations, provided misleading translations and superficial information that have played a vital role in hindering the understanding of science concepts by Saudi teachers and their students (Al-Ghanem, 1999; Kashgary, 2011).

7.2.2 Language and Terminology

Modern Standard Arabic dates back to the early 19th century (Shah, 2008) and is the official language in Saudi Arabia, Bahrain, Qatar, Oman, Kuwait, United Arab Emirates, Egypt, Iraq, Jordan, Syria, Lebanon, Palestine, Yemen, Algeria, Morocco, Eritrea, Comoros, Tunisia, Chad, Libya, Djibouti, Mauritania, Sudan, Somalia and Western Sahara (Bahloul, 2007). Language and terminology can sometimes be confusing and can increase the occurrence of misconceptions among high school students. The next sub-section provides examples of how language and terminology have shaped students' understanding of thermal concepts and how they may have advance the proliferation of false beliefs schemas and thereby hindered conceptual change.

Example 1: 'Heat and temperature are the same thing'

In the English language, 'heat' and 'temperature' are denoted by different terms that are made up of different phonetic sounds. The confusion that Western students experience in dealing with these terms does not stem from phonetics but from associated meanings in cases wherein students believe temperature to be a measurement of heat (Yeo & Zadnik, 2001). By contrast, Modern Standard Arabic represents 'heat' and 'temperature' with the same phonetic sound and the same character (shape); this sound and character denote the Arabic terms 'heat' and 'heat degree'. This identically gives the impression that heat degree is the measurement of heat intensity. As shown in Table 7.13, most modern languages around the word represent ‘heat’ and ‘temperature’ using different sounds and letters, but in the Arabic language, only one sound is used to refer to the two terms. Differentiation between the two is done by attaching the word ‘degree’ in front of ‘heat’ to produce the word ‘temperature’. Unsurprisingly, therefore, Saudi teachers and students generally confuse these terms. As previously indicated, ‘temperature’ does not exist in the vernacular language of Arabian countries.

Table 7.13 *Heat and temperature, as written in Arabic and other languages*

English	Heat	Temperature
Arabic	الحرارة	درجة الحرارة
French	Chaleur	Température
German	Hitze	Temperatur
Dutch	Warmte	Temperatuur
Spanish	Calor	Temperatura
Korean	열	온도
Indonesian	Panas	Suhu

Note: All textbook statements in Tables were taken verbatim from sources.

Example 2: ‘A cold body contains no heat’

Another example is the term ‘zero’, which refers to ‘nothing’ in Arabic; this mathematical term was originally crafted to refer to ‘absolutely nothing’ or ‘absolutely empty’ (Institution, 1903, p. 518). Arabs therefore interpret 0°C as pertaining to ‘no heat’ simply because from their perspective, when a hot object turns cold at this temperature, it loses all its heat. Additionally, when ordinary Arab people talk about ‘heat’, they refer to something external to an object’s body that ‘add[s] heat, lose[s] heat, increase[s] heat, decrease[s] heat, gain[s] heat’ and not as an internal (kinetic and potential) component of molecules' energy. This understanding of 0°C appears to be non-negotiable and widely accepted by many Saudi teachers and students. In the pre- and post-tests, therefore, the students chose the option 'a cold body contains no heat' as their response to five questions in the TCE (Q7, Q10, Q11, Q22 and Q26). In other words, up to 72% of the students expressed belief in the statement in the pre-test, and up to 71% of them exhibited such belief in the post-test.

Example 3: 'Skin or touch can determine temperature'

The Arabic language features a variety of expressions for describing temperature during hot weather or the temperature of hot objects. There are 21 such expressions in old Arabic dictionaries, but the language features only seven expressions for describing the temperature of cold weather or cold objects. This attribute is logical given that the majority of Arabian countries have hot weather year round.

Most of these expressions have vanished from everyday language and can be found only in dictionaries or the literature (Kashgary, 2011). All these expressions also depend on a person's sensation and how he/she can differentiate among a vast range of temperatures by touch. Four-fifths of the pre-test respondents and over two-thirds of the post-test respondents exhibited the false belief that 'skin or touch can determine temperature' (see Table 7.14). An Arab uses his/her senses to differentiate between the temperatures of two objects. Apart from medical thermometers, no other temperature measurement devices can be found in most Arab households. Even television shows or cookbooks do not require the use of a thermometer to measure temperature (Teacher #6, personal communication, 2015).

Table 7.14 *Determination of temperature by skin or touch in the Arabic language and % of students believe on it*

	Arabic language						
Heat	دافِئ	لاهب	حُرْقة	حَمْي	حَمَاوَة	حَمَارَّة	حَرّ
	حام	لافحٌ	قَيْظ	فَيْح	صَيْهَد	هَجِير	وَهْج
	سعير	أوَار	ساخن	رَمْضَاء	نار	صال	إحْتِدَام
Cold	صقيع	قرس	قَرٌّ	صَرْدٌ	صرصر	بُرُودَة	زمهريرٌ
MC	Skin or touch can determine temperature.						
TCE	Q16. Kim takes a metal ruler and a wooden ruler from his pencil case. He announces that the metal one feels colder than the wooden one. What is your preferred explanation? a. Metal conducts energy away from his hand more rapidly than wood. b. Wood is a naturally warmer substance than metal. c. The wooden ruler contains more heat than the metal ruler. d. Metals are better heat radiators than wood. e. Cold flows more readily from a metal.						

Q16 incorrect answers %	Pre-test	Post-test
Option (b+c+d+e)	80%	69%

Note: All textbook statements in Tables were taken verbatim from sources.

Example 4: 'Steam is more than 100°C'

As it can be seen in Table **7.15**, the Arabic language accords 'vapour' and 'steam' the same phonic sound, with the only difference between the two being that 'steam' is represented as a noun and as a more general word than 'vapour' and that 'vapour' is represented as an adjective and, sometimes, as a verb (same spelling, different pronunciation). In the current work, up to 90% of the pre-test respondents and up to 83% of the post-test respondents expressed the belief that 'steam is more than 100°C', indicating how this false belief has become implanted in Saudi students' minds.

Table 7.15 *Confusion over vapour and steam in the Arabic language expressed into incorrect answers %*

English	Vapour	Steam
Arabic	تبخر	بخار
MC	Steam is more than 100°C (p.498)	
TCE	Q6. What do you think is the temperature of the steam above the boiling water in the kettle? a. 88°C b. 98 °C c. 110 °C d. 120 °C	Q19. Ron reckons his mother cooks soup in a pressure cooker because it cooks faster than in a normal saucepan but he doesn't know why. a. Emi says: "It's because the pressure causes water to boil above 100°C." b. Col says: "It's because the high pressure generates extra heat." c. Fay says: "It's because the steam is at a higher temperature than the boiling soup." d. Tom says: "It's because pressure cookers spread the heat more evenly through the food."
Test	<u>Q6 option (a+c+d)</u>	<u>Q19 option (b+c+d)</u>
Pre	83%	90%
Post	83%	83%

Note: All textbook statements in Tables were taken verbatim from sources.

The confusion between the terms has given rise to numerous misunderstandings of the interpretations appearing in many scientific papers written by Arabian educators. In their recently published paper, for instance, Nawafleh et al. (2016) interpreted an incorrect notion held by students and listed in Yeo and Zadnik (2001)—that is, 'steam is more than 100°C'—by saying that students believe in this statement because they have forgotten that steam (vapour) can occur at any temperature (Nawafleh et al., 2016). This explanation, which considerably deviates from the intended meaning, was caused possibly by confusion over terminology.

7.2.3 Teachers' Practical Knowledge

As previous studies have shown, teachers' practical knowledge is a combination of their personal beliefs, formal information and experiential knowledge (Ball & Cohen, 1999; Haney, Czerniak, & Lumpe, 1996; van Driel et al., 2001). Research in teachers' practical knowledge shows that even the most experienced teachers are resistant to altering their existing practical knowledge (van Driel et al., 2001). Recently, the Saudi Department of Education adopted an American physics textbook that was created to meet American standards and written to apply a certain teaching and learning philosophy (i.e. inquiry learning), although applying the new learning and teaching strategies is not compulsory (Teacher # 8, personal communication, 2015). Even though some Saudi teacher training materials were supposed to be based on modern teaching and learning strategies (e.g. reflective thinking, scientific reasoning, and analysis and in-depth interpretation of scientific knowledge) with the stated goal to scaffold teachers' concept understanding from explaining to self-knowledge (based on the six facets of understanding in Wiggins and McTighe (1998), those training materials did not go beyond the traditional teaching and learning approach. For instance, in their work, Alruhaily (2011) explained several experiments to enhance teachers' understanding of science concepts covering four topics: astronomy, chemistry, biology and physics. Some of these experiments are presentation experiments in which the trainer presents the experiment in front of the entire group and asks questions such as 'What do you expect to happen when you test the electrical conductivity of a salt and sugar solution? Explain' (Alruhaily, 2011, p. 77). This approach induces teachers to recall the old information they already know without adding any extra information. In another example, under the Mechanics Concepts session, Newton's second law of motion is provided for teachers to read as follows:

'The acceleration of a system is directly proportional to and in the same direction as the net external force acting on the system, and inversely proportional to its mass' (Alruhaily, 2011, p. 50).

This definition of Newton's second law is then followed by this simple question: Which Figure, (A) or (B) as shown in Figure 7.2, follows Newton's second law? (Alruhaily, 2011, p. 50).

Figure 7.2 A question listed in (Alruhaily, 2011, p. 50)

This type of simplified question does not apply any more than the traditional teaching and learning approach based on memorisation and is far removed from the modern teaching and learning strategies those authors listed in their book. In another example regarding solubility, a Table with a full reading of temperature and solubility was provided, and the teachers were tasked with drawing a graph to show the relationship between the two measures (see Alruhaily et al., 2011, p. 74). In another example about solubility and electric conductivity, teachers were asked to observe the results of a simple experiment to test the electric conductivity using a very simple circuit. Following the experiment, teachers were asked to answer simple questions that did not go beyond the memorisation level (see Alruhaily et al., 2011, pp. 77–78).

Another example comes from observing one of the largest learning programs called iDiscover, run by the biggest oil company in the Middle East (i.e. Aramco Company), with teachers who had been trained by University of Berkeley-Lawrence Hall of Science, Math Zoom, and a network of global experts (Saudiaramco.com, 2017). Started in 2012, the iDiscover program aims to increase knowledge among Saudi teachers and students using an inquiry-based learning approach, and promote critical thinking, creativity, innovation and real-world problem solving skills (iThra Youth, March, 2013). Since then, hundreds of thousands of students and teachers have been taught by the program (Saudiaramco.com, 2017). As observed in 2015 that in one of these training sessions, the trainer used a Bernoulli principle experiment to explain the effect of the absence of gravity (Teacher #5, personal communication, iDiscover, 2015). In another session, a trainer incorrectly discussed the lifecycle of a star by showing a graph that provided two possible paths for the star to go through when born (as shown on Choolsobservatory.org)—white dwarf or supernova—but reading the graph as if it was one path in one circle. In another iDiscover program session, the trainer described the sun as a planet multiple times, provided false information (e.g. all the elements in this universe are founded in human DNA) and referred to seasons as a cause of the Earth's orbit shape (Teacher #5, personal communication, iDiscover, 2015). To this end, it seems even the powerful training program (i.e. iDiscover) does not affect teachers' practise much simply because such training does not take into account teachers' practical knowledge, which is a combination of their personal beliefs, formal knowledge and experiential knowledge (van Driel et al., 2001). These examples may explain why conceptual change is not easy to achieve with such ingrained ideas.

7.3 Summary

This chapter concentrated on responses to Research Question 4, which revolves around the possible sources of misconceptions held by Saudi female high school students and their teachers regarding thermal concepts. Besides language barriers that have been discussed in Chapter 6, three other possible sources were discussed in this chapter: Saudi physics textbooks, language and terminology, and teachers' practical knowledge. Evidence was provided throughout the chapter to support the role of these three sources as impediments to conceptual change because of the way terms of thermal physics are rendered in Arabic, with practically no clear distinctions in meaning, spelling, or pronunciation. The content review of the Saudi physics textbook revealed the potential of the material to provide ambiguous, inconclusive, missing, contradictory, and irrelevant information.

CHAPTER 8
DISCUSSION, CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

8.1 Introduction

The conceptual change approach can help educators and psychologists understand how knowledge is constructed by students and teachers, how these constructs change when students or teachers come across to-be-learned concepts that contradict old schemas, and the difficulties they may face during the process (Vosniadou, 2013). Thus, this study was designed and delivered to examine the female Saudi students' and their female teachers' understanding of thermal concepts; whether these concepts have been conceptually understood; and, if not, why. Four research questions and three sources of data (the TCE instrument, a professional development workshop, and a review of possible sources of students' misconceptions) were used to analyse conceptual change amongst female Saudi students and their female teachers, in order to answer the main research question.

This chapter is constructed as follows: Section 8.2 covers in details the discussion of the major findings related to the RQ1, Section 8.3 discuses RQ2, Section 8.4 discuses RQ3 and Section 8.5 covers RQ4. Section 8.6 discusses the overall findings of the study. Section 8.78.7 and Section 8.8 cover the limitations and recommendations of the study, respectively. The study's main research question was as follows: What is the level of thermal energy concepts understanding exhibited by Year 11 Saudi female students and their teachers in the Eastern Province of Saudi Arabia?

8.2 Response to Research Question 1: What thermal concepts are understood scientifically by Saudi female high school students before and after instruction?

Misconceptions of TCE often involve either inaccurate or incommensurate knowledge. *Inaccurate knowledge* pertains to false belief schemas that are incorrect ideas, as defined by Vosniadou (2013). On the other hand, *incommensurate knowledge* involves category mistake schemas, which are robust beliefs that prevent conceptual change from occurring. The gravity of category mistake schemas comes from their being incorrectly assigned to unsuitable ‘lateral’ categories (Vosniadou, 2013). Between the two categories, female Saudi students struggled to develop the new schemas, and were also unaware of the conceptions they had that did not fit with modern scientific theories. Table 6.10 in Chapter 6 listed an example of each concept (a false belief schema and a category mistake) based on TCE questions.

Research Question 1 was illuminated on the basis of the data collected from the pre-test and post-test responses to the first mean, which was the TCE by Yeo and Zadnik (2001). This test covered 35 misconceptions in the following four categories: (A) the students’ conceptions of heat, (B) the students’ conceptions of temperature, (C) the students’ conceptions of heat transfer and temperature change, and (D) the students’ conceptions of the thermal properties of materials. As Figure 6.2 in Chapter 6 demonstrated, Category A questions received the lowest percentage (71%) of misconceptions as responses, whereas Category B questions received the highest percentage (80%). This is understandable to some degree because Category B revolved around the students’ conceptions of temperature as shown in Yeo and Zadnik’s (2001) misconceptions list. This study uncovered the fact that the term *temperature* does not exist in the participants’ vernacular language (as shown in Chapter 4, Section 4.7).

With respect to conceptions of thermal properties of materials, the students registered a high percentage of misconceptions listed in Yeo and Zadnik (2001). As Table 6.10

in Chapter 6 illustrated, most student errors were related to false beliefs; few were related to advanced errors such as those belonging to category mistakes. In addition, language has played a role in learning and maintaining scientific knowledge, as discussed in Chapter 6, Section 6.2.

On the other hand, data analyses in Chapter 7 uncovered the role that Saudi physics textbook plays in promoting misconceptions amongst female Saudi students, as well as the role that terminology plays in confusing students and preventing them from acquiring reasonable scientific knowledge. The highest percentage of misconceptions revolved around heat and temperature, which was not surprising. Alwan (2011) and Nawafleh et al. (2016), who used TCE in their studies, found that many of their Arabian student respondents believed that ‘water cannot be at 0°C’ (see Yeo & Zadnik, 2001, p. 498). Almost 40% (in the Alwan study) and over 60% (in the Nawafleh et al. study) of respondents believed in this misconception. In addition, Chu et al. (2012), who also used TCE, reported almost the same percentage amongst their study’s respondents as that of the Saudi students who believed the alternative concept that ‘ice is at 0°C and/or cannot change temperature’ (see Yeo & Zadnik, 2001, p. 498). The mentioned percentage of students in all of these studies believed that 0°C is the lowest temperature that ice can attain, regardless of its surrounding temperature.

Most previous studies that used TCE did not provide enough justification for why their respondents offered answers that could help in comparing the origins of these schemas. Luera et al. (2005), however, presented justification for their American students’ answers. The performance of these students in Q8 and Q19 of their TCE was attributed to the fact that none of the respondents had experienced cooking at high altitudes (i.e. Q8), and that only two of them even knew what a *pressure cooker* was (i.e. Q19).

Similarly, the majority of Saudi teachers' and students' responses shared the same misconception (as outlined in Chapter 6, Sections 6.2–6.4). Chu et al. (2012) indicated that their studied participants were familiar with the concept of phase changes. However, a significant number of the Chu et al. (2012) study participants expressed the belief that boiling temperature does not remain constant during the boiling process and that the temperature of the steam rising from boiling water is higher than that of the water itself. The authors attributed these beliefs to insufficient information given about these concepts in the participants' curricula and a lack of involving more explanations and discussions regarding everyday phenomena. The Saudi students provided almost the same misconceptions as those selected by the Chu et al. (2012) study's respondents.

In most cases, the respondents in the Hadžibegović and Sulejmanović (2014) study strongly favoured one misconception, whereas the Saudi students chose three to four misconceptions, which they also selected in their post-tests (as shown in Chapter 6, Table 6.3). Instruction, culture, or training (or perhaps all these factors) drove the Hadžibegović and Sulejmanović (2014) study's respondents to select one answer to most of the questions. In contrast, the Saudi students tended to choose many different responses—a tendency that may stem from their habit of memorising and reproducing verbatim information they receive in school (Oyaid (2009). These students failed to understand that applicability depends on context. Predilection for memorisation is not restricted to Saudi students, but it is a habit of most Arabian people, as discussed in Za'rour (1975), Alwan (2011), and more recently Hayes, Mansour, and Fisher (2015).

The widespread misconceptions investigated in this study have been reported regularly by researchers around the world. Saricayir et al. (2016), for example, found that the students they interviewed believed heat and temperature were the same thing. According to Taştan, Yalçınkaya, and Boz (2008), the studies carried out by Erickson (1979); Erickson (1980), Harrison et al. (1999), Paik, Cho, and Go (2007), and Başer and Geban (2007) indicated that students used the terms ‘heat’ and ‘temperature’ interchangeably.

In short, female Saudi students and teachers demonstrated that they hold similar misconceptions that have been reported in many studies throughout the world. However, as discussed in Table 6.3 in Chapter 6, the high prevalence of misconceptions amongst Saudi students that prevent their understanding from going beyond the superficial can be ascribed to a number of factors. For instance, the nature of certain misconceptions, particularly those that have descended into ontology trees, makes them hard to change (Chi, 2013). As this study found that, ambiguous textbook language, confusing terminology, and language barriers might played a critical roles in the occurrence of Saudi female students’ thermal misconceptions.

The second research question discusses the level of female Saudi high school students’ scientific understanding of thermal concepts after such concepts are taught to them.

8.3 Response to Research Question 2: What misconceptions are formed by Saudi female high school students about thermal energy before and after thermal energy instruction?

To discover thermal concepts that are understood scientifically by female Saudi high school students, pre-test and post-test data obtained from the TCEs were analysed. As shown in Table 6.4 of Chapter 6, 15 of the 26 questions in the TCE recorded an improvement in the post-test of up to 11%. The questions with the five highest percentage improvements were those that dealt with *false belief* schemas (Q2, Q14, Q15, Q16, and Q19). From Chi's (2013) point of view, false beliefs are usually easier to change using scientific schemas. For instance, in Q2, which measured whether students conceptually understood that 'water can be found at 0°C', the post-test record increased by 9%. This result suggests that more students believed that water can be found at 0°C *after* being instructed by teachers who attended the workshop, allowing the number of Saudi students who believed in the new schema to rise to 28%. Similarly, in the Chu et al. (2012) study, participants exhibited a high response to the same concept—up to 58% amongst Year 11 students particularly. In addition, Alwan (2011) and Nawafleh et al. (2016) found that only around 37% of their university students believed in this correct concept.

Undoubtedly, female Saudi students showed the lowest percentage of correct answers amongst all of the studies' participants. There could be many reasons for this, such as language barriers or ambiguous scientific language in textbooks and terminology, as discussed in Chapter 7, Section 7.1. However, the increase in the percentage of students who believed in the scientific concepts suggests that this can be accelerated using designed instructions and conceptual change strategies, as posited by Posner et al. (1982), Vosniadou (2013), Chi (2013), and Duit et al. (2008). In addition, Chi (2013) suggested promoting conceptual change by explicitly or implicitly refuting false belief schemas so that they become more scientifically correct ones. An example of explicit refutation in this case is that 'water can be found at 0°C'. Examples of implicit refutation include discussing the definition of heat of fusion or an experiment as discussed in Chapter 6, Section 6.1. On the other hand, Table 6.4 illustrated that Q15 and Q16 acquired the highest positive change percentages of up to 10% and 11%, respectively. Question 15 pertains to heat transfer and temperature changes. It seems that more students, after being instructed, believe that heat is not proportional to temperature and that a temperature of 5˚C, for instance, is not twice as cold as a temperature of 10˚C.

Question 16 examined heat conductivity and equilibrium. Since the beginning of humanity, humans have used their senses to discover the world around them, including the use of touch to determine temperature. This practise worked for many centuries; however, it is not accurate and not practical in many cases today. After being instructed, more female Saudi students (11%) successfully changed their old schemas of the effectiveness of using touch to determine temperature.

On the other hand, Figure 6.2 in Chapter 6 demonstrated that Category A students' conceptions of heat received the lowest misconception responses from the female Saudi high school students, indicating that this is the category in which the students provided the highest number of scientific responses in the post-test. In addition, Table 6.3 illustrated that under the same category A, the highest proportion of scientific responses was provided for the question attached to 'heat is a substance' (54%), followed by the statement 'heat is not energy' (36%). These statements appear to be two sides of the same coin; that is, if a student believes heat to be a *substance*, then he or she must also be of the opinion that heat is not a form of energy, and vice versa.

The results for the 'heat is not a substance' statement amongst the students are unsatisfactory, given that almost half of the students still believe the opposite. It is also somewhat surprising because female Saudi high school students are typically taught that heat is not a substance, it is a form of energy (Teacher # 5, personal communication, 2015). This difference can be directly linked to ambiguous terminology; certain words translated from English to Arabic are not based on accurate Arabic meanings. For example, 'substance' in English translates to 'material', which is used as an Arabic counterpart of a wide range of English terms, especially those used at schools. Using the statement 'heat is a material' as a translation of the alternative concept 'heat is a substance' creates difficulties in the efforts of Saudi students to accurately grasp the concept of heat. Thus, female Saudi students often experience problems in understanding abstract terms because they do not come across these terms in their daily lives. Language barriers and scientific language difficulties prevent students from using scientific terms in relation to everyday life events.

8.4 Response to Research Question 3: What is the level of thermal conceptual understanding exhibited by Saudi female high school teachers?

This question concentrates on female Saudi teachers' understanding of thermal physics. To elucidate this issue, results from the Saudi Teacher Professional Development Workshop and teachers' interviews were analysed. As indicated in Table 5.2, multiple attempts (up to 13 in some cases) were required to help teachers grasp the scientific concepts during the workshop, without telling the teachers that this schema does not fit with modern science theories or that they should replace the old schema with the new one on their own. It was assumed that after all these attempts to challenge the teachers' thinking about thermal physics misconceptions, the old schemas would change. However, results of the focus group discussions and teacher interviews showed no significant change in teachers' knowledge. The most disturbing aspect of this issue is that textbooks and other science materials do not help teachers correcting unscientific ideas that they may have had for a long time.

As shown in Chapter 6, Section 6.4, 50% of the studied teachers stated that water must reach a temperature of 100°C for it to evaporate. In communities where thermometers are rarely used in daily life, people often experience difficulty examining the temperatures water needs to reach in order for it to steam or to evaporate. More explanations on how textbooks contribute to the proliferation of such mistakes have been provided in Chapter 6. The results of the Saudi teachers' interviews and focus group discussions revealed a low level of understanding of most physics concepts related to thermal energy. This can be ascribed to sources of the students' misconceptions as discussed in Chapter 6, Section 6.3, such as the ontological nature of some concepts, language barriers, terminology, and the ambiguous language of Saudi physics textbooks. If teachers' lack of training added to these factors, then the aforementioned performance is a logical outcome. Za'rour (1975), Duit et al. (2008), and Helm (1980) argued that teachers cannot be blamed for the misconceptions that students form in their minds if they themselves are unaware of the existence of such misconceptions.

8.5 Response to Research Question 4: What are the possible sources of Saudi female high school students' misconceptions regarding thermal physics?

As discussed in Chapters 6 Chapter 6 and 7, a number of specific factors may have contributed to female Saudi students' low achievements in this scientific diagnostic test on thermal physics. These factors include ambiguous scientific language, the ontological nature of some concepts, language barriers, and terminology. For conceptual change to occur, students must be aware of their old schemas that do not correspond to modern scientific theories, and they must become knowledgeable of the correct ones (Chi, 2013). The nature of several old schemas that descend from ontology trees, however, makes changing such schemas very difficult. This is particularly true when using traditional learning and teaching strategies, such as the well-known memorisation strategy in Saudi government schools (Gafoor & Akhilesh, 2010). Some of the misconceptions related to thermal concepts are either at a false belief schema level or a category mistake schema level. As indicated by Chi (2013), false belief schemas are more likely to change to more scientific ones using either explicit refutation or implicit refutation strategies. However, dealing with more advanced schema categories, such as category mistake schemas, requires more than direct refutation due to their descent from ontology trees. This was specifically investigated, and the roots of several thermal misconceptions have been sorted into their mental models (e.g. false beliefs and category mistakes) as shown in Table 6.10, where seven misconceptions are defined as category mistake schemas, and 28 are defined as misconceptions for a total of 35 misconceptions, listed by Yeo and Zadnik (2001).

Moreover, the Modern Standard Arabic language, which is used in school and everyday life (e.g. vernaculars), may be a source of Saudi student misconceptions. Modern scientific knowledge revolves around innovations that are mostly described in terms that do not have counterparts in official or everyday Arabic language, as discussed in Chapters 4 and 6. Correspondingly, early translators borrowed words from formal Arabic and 'forced' meaning into these new words that do not occur in daily spoken Arabic. This ambiguously translated language creates difficulties in grasping the actual meanings of words and concepts for the majority of Saudi students who mostly speak vernacular languages. Such an initiative perpetuated the gap between what students learn in school and what they practise in everyday life. It also contributed to the student misconceptions reported by Chu et al. (2012), who found that different meanings are often assigned to the same concepts in everyday and academic languages – in this case, Korean students' misconceptions have naturally led to student errors in their responses to TCE instrument.

Similarly, Jasien and Oberem (2002) pointed out terminology issues as sources of students' misconceptions regarding thermodynamics. Moreover, as mentioned in Chapter 3, the capacity of the vernacular language in most Arabian countries does not exceed 3,000 words, and the official language does not exceed 6,000 words, resulting in a limited vocabulary for the Arabian people for understanding and expressing that understanding of knowledge around them, including Western scientific material (Al-Sukkari, 2014). In addition, as discussed in Chapter 6, the physics textbook used by Saudi Year 11 students is one of the most significant sources of misconceptions of thermal concepts. The current study investigation revealed that ambiguous language and misleading or inaccurate information and translation of textbooks could have been responsible for Saudi students' low achievements in the TCE diagnostic test.

8.6 Conclusions

There are two phases of conceptual change in learning modern science: assimilation and accommodation (Posner et al., 1982). Each of these phases discusses different ways in which students should deal with to-be-learned concepts. The first phase, *assimilation*, occurs when students use existing concepts as a background for comprehending new phenomena (Posner et al., 1982). The second phase, *accommodation*, occurs when existing concepts are inadequate for grasping new phenomena successfully. Thus, the central concepts have to be reorganised or replaced (Posner et al., 1982). On the other hand, Duit et al. (2008) asserted that in order for conceptual change to occur, the satisfaction of students with their old schemas must be low, and the satisfaction of students with their new schemas must be high. Chi (2013) pointed out that in order for conceptual change to occur, students must be familiar with their faulty schemas and must be knowledgeable about the correct ones.

Vosniadou (2013) argued that science concepts in the beginning are often mistakenly assigned to a different physics and mathematics framework than was intended, which makes them challenging to learn. This argument highlights the importance of understanding how students construct, apply, and learn, as well as the difficulties that may hinder their knowledge processes when they learn about new scientific concepts (Vosniadou, 2013).

This chapter has responded to the four research questions pursued in this study that revolve around Saudi students' misconceptions of scientific knowledge, their teachers' levels of understanding, and the possible sources of the misconceptions. These issues were discussed using different data sources. The major question of this study pertained to female Year 11 Saudi students' and their teachers' understandings of thermal energy. This chapter presented a number of studies performed by different nations between the early 19th century and the present. By 2004, nearly 6,000 publications about students' ideas had been released (Chi, 2008). The literature review traced the development of the term 'misconception' and how the basis of students' prior knowledge has shifted from superstitions and misconceptions to alternative beliefs. Almost all the reviewed studies suggested the use of different teaching and learning techniques as the ultimate solution for converting erroneous prior knowledge to correct knowledge. Most of the recommended techniques involved challenging prior knowledge, especially amongst Westerners. Some studies, such as that of Prince et al. (2012), demonstrated minimal improvement in students' understanding of concepts. Others, such as that of Thomaz, Malaquias, Valente, and Antunes (1995), reported a decline in their participants' levels of understanding after receiving instruction. However, in some cases, participants' misconceptions remained at the same level after instruction (Louzada et al., 2015). Some of the reviewed literature reported more than a 90% occurrence of misconceptions or misconceptions amongst study participants. The highest rate of misconception in some questions was reported by Alwan (2011), whose occurrence rate in some cases was 100% amongst university students.

Nearly all the reviewed studies indicated that the sources of misconceptions were the same the world over, with the exception of Za'rour (1975), who differentiated between Western and non-Western sources. Similarly, the current study investigated misconceptions and their sources in non- western students amongst female Saudi students. Madu and Orji (2015) provided one of the few reviewed works that implemented the learning situation models discussed by Chi (2008). Almost all the reviewed studies used students’ correct answer percentages as indicators of the presence of misconceptions, with the exception of Al-Rubayea (1996), Nawafleh et al. (2016), and Alwan (2011), who all concentrated on incorrect responses. The current study also focused on erroneous answers as indicators of unsuccessful conceptual change and on correct answers as concepts understood by students.

Some of the reviewed studies linked the presence of misconceptions to the students’ intelligence (Garrett and Fisher (1926), mathematical skills (Halloun and Hestenes (1985), and critical thinking skills (Abdel-Wareth and Saeed (2012). Others showed increases in correct conceptions in studies that used a cross-age approach and decreases in the rate of misconceptions, such as studies by Doran (1972) and Georgiou and Sharma (2010, 2012). Little to no cross-age improvement was observed by Chu et al. (2012), Jasien and Oberem (2002), and Prince et al. (2012). By combining the current work, which investigated high school students’ understandings of thermal concepts, with the research of Nawafleh et al. (2016), who probed into university students’ comprehension of thermal concepts using the TCE instrument, it may be concluded that no cross-age improvement occurred in terms of misconceptions regarding thermal energy. This is supported by the findings of Za'rour (1975), who also found no such improvement amongst Years 9 and 11 in Lebanon or amongst Lebanon's university students regarding science concepts.

A limited number of studies were devoted to the potential of textbooks for containing misconceptions and ambiguous language, such as Aycan et al. (2002), Kavşut (2010), and Weaver (1965). However, no review was performed for McGraw-Hill science textbooks in either Arabic or English. It is hoped that the review in Chapter 6 of this thesis will fill this gap.

Possible sources of students' misconceptions in textbooks were examined by Yahiel (2009), who explored the impact of language and terminology in students' misconceptions; Weaver (1965), who investigated an American science textbook series; Kavşut (2010) and Aycan et al. (2002), who investigated a Turkish science textbook series; and Deshmukh and Deshmukh (2011), who investigated an Indian science textbook series.

A study by Wiseman and Al-bakr (2013) found that there was no relationship between the achievement levels of Saudi students and their teachers' educational levels. Studies that were mostly conducted in Arab countries, such as those of Nawafleh et al. (2016) and Za'rour (1975), showed no cross-age improvement in students' understanding of scientific concepts, nor a decline in the presence of misconceptions/alternative conceptions amongst students in different years. Nawafleh et al. (2016) and Za'rour (1975) results also indicated that university students' understanding of scientific concepts is almost the same as that of Saudi female high school students.

A number of researchers (Ahmad, 2006; Al-ghaleeth, 2008; Al-Rashed, 2002; Aldahmash & Alshaya, 2012; Assoleem, 2002; Hola & Al-Mutairi, 2010; Matter, 2010) who focused on Arabian countries found a strong prevalence of misconceptions/alternative conceptions amongst Arab students. Alwan (2011) discovered a 100% occurrence of some misconceptions in a TCE that he administered to university students.

The current research used a theoretical framework based on the learning model put forward by Chi (2013), Vosniadou (2013), and Duit et al. (2008), who encountered cases wherein individuals may have had no prior understanding of how to learn new concepts. References were also made to the works of Hewson and Hamlyn (1984) and Sanbonmatsu et al. (1992) for information on the missing prior knowledge model. The study revealed widespread alternative conceptions amongst female Saudi high school students and their teachers, as well as the difficulty of changing most of these alternative conceptions using traditional learning and teaching strategies. The level of conceptual understanding of thermal concepts was very low. These findings can be interpreted as the nature of most thermal alternative concepts that have their roots in ontology trees, which makes these concepts difficult to change in a traditional manner.

In addition, language barriers play a significant role in preventing Saudi students and their teachers from acquiring optimal scientific knowledge. In many Saudi villages, it is common to speak in a vernacular language, most of which is very old or belonged to languages that are now dead. This in particular shows how the old vernacular language capacity is limited and does not have an equivalent in most modern scientific concepts, giving further evidence of how difficult it often is for Saudi students to grasp scientific knowledge. Moreover, the ambiguous language of Saudi physics textbooks and terminology may promote false beliefs and misconceptions amongst Saudi students and their teachers. These two sources—the nature of the concepts that are impacted by language barriers, and the ambiguous language of textbooks and terminology—shape the two ends of the enclosure that prevents Saudi students from understanding thermal concepts.

The present study sheds light on female Saudi high school students' misconceptions of thermal physics. Studies grounded in the conceptual change approach can advance our knowledge of how individuals understand science, why scientific concepts that could ease everyday challenges are rarely applied, and other disciplinary information. Additionally, such explorations can give rise to new wide-ranging research directions for those who believe in the value of using the conceptual change approach.

Understanding the conceptual change approach and its role in delivering new ideas that align with modern scientific views is very important and should therefore be incorporated into teachers' training programs. On a larger scale, the Saudi Department of Education has been encouraged to adopt learning and teaching theories as well as an educational philosophy in order to establish plans with a strong foundation and to help Saudis thrive in the surrounding markets.

8.7 Limitations

Number of schools

Saudi Arabia is home to 5,307 secondary schools, 649 of which are located in the Eastern Province alone (Ministry of Education-Elsharqia, 2010). This study was conducted in five of these institutions that completed the pre-tests and post-tests. Because this proportion represents 0.7% of the total number of secondary schools in

Saudi Arabia's provinces, the sample may not reflect the reality in the entire country's schools.

Teachers' experience

The superficial student achievement in Saudi Arabia may also be explained by Saudi physics teachers' experiences and qualifications. With respect to experience, Saudi teachers work as pre-service teachers, novice, experienced instructors, or out-of-field teachers. In this study, teachers' experiences rang was between one year up to 25 years. Regarding the effect this factor in teachers understanding of thermal concepts, it's seems some experienced teachers failed to answer a certain questions that designed to develop students understanding of thermal concepts during the workshop that took place before administrating the TCE to students.

Variations in instruction across the different schools.

This factor is not separated from the previous factor where both are linked to each other. The fact that each teacher have her own style in delivering information to her students, her skills and her level of understanding of physics concepts, has to do also with teachers' experience. There was no monitoring during collecting the data of how teachers delivered, implemented the new information that they received during the workshop to their students or the accuracy and the quality of such information. These variations may effect students' achievement of TCE.

Published research on female education

Another limitation is related to Arab and Saudi published literature, especially from universities where the jobs of faculty members are mostly limited to lecturing. Illuminating the research culture of Arab regions is important, particularly in Saudi Arabia, which is considered an education leader in the Arabian region, with academics responsible for younger generations' education.

Another example of the ambiguity in Saudi research culture is the establishment of science standards for textbooks that match those of Western textbooks, not the other way around.

Workshop time

The teachers' workshop only lasted three days, which may have limited teachers' understanding and ability to cope with the amount of new information they were given.

8.8 Recommendations

For Saudi curriculum authorities

The conceptual change approach is an important method of challenging and correcting the old schemas that teachers and students have been using with new schemas that align with modern scientific theories. Thus, establishing a curriculum and creating textbook materials on the basis of students' misconceptions may be insufficient without training teachers on how misconceptions work, how humans think, how students structure their knowledge, and how they respond to new knowledge provided by teachers. Such training is crucial in the effort to improve teachers' and students' understanding of science concepts.

For the Saudi Ministry of Education

The Saudi Ministry of Education should highlight issues such as accuracy of the content and the reliability of textbook translation, discuss amendments with the Saudi publishing company and their partner McGraw-Hill, and review again the Arabic copies of the textbooks to identify and avoid mistranslations. McGraw-Hill is also strongly advised to provide review of the current textbooks' versions using expert translators so that the company can continue to provide its services to Arabian countries.

For Saudi female teachers

Teachers' practical knowledge, which is shaped by teachers' formal knowledge, personal beliefs, and experiential knowledge, must be considered in any attempt to change their conceptual understanding of any topic. In this regard, future researchers are highly recommended to recruit a larger sample of participants to increase the scope of schools that are involved.

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APPENDICES

Appendix A Interview Protocol

In order to scrutinise, clarify, probe and enhance Saudi female teachers understanding of thermal concepts, semi- structured interview has been used. Examples of interview questions that used to guide the one-on-one interviews are similar to the following questions.

English version of teacher interview questions (Examples)

1. What is the temperature of water vapour in this case? [Showed a picture]
2. Do you think the picture that shows water boils at 50 °C is incorrect?
3. If we consider that the stove is not shown, how do you explain the temperature being labelled as 50 °C?
4. How is air pressure decreased?
5. What happens to air pressure when we climb a mountain?
6. Why do people feel uncomfortable when they climb a mountain?
7. My question is can water boil at 50 °C?
8. About the teapot on the mountain—if the water boil at 50 °C, what is the temperature of the steam that is produced by boiling?
9. Do you think the boiling point is always 100 °C?
10. Is there any case where water can boil at temperatures less than 100 °C? For instance, 98 °C.
11. What is the relationship between the boiling point and pressure?
12. What do you know about pressure cookers?
13. Just state the opposite of the statement I said earlier.

14. Pressure changes when height changes. Does it increase or decrease with height?
15. If the water boils at 50 °C, what is the temperature of the vapour produced by boiling?
16. If water boils at 75 °C, what is the temperature of its steam?
17. When water boils, what is its temperature?

Arabic version of teacher interview questions (Examples)

☞ <u>امثله لمناقشة الاستيعاب المفاهيمى لمفهومى الحرارة ودرجة الحرارة:</u>

1. كيف تفسري ان درجة الحرارة ٥٠ في الرسم
2. كيف ينخفض الضغط
3. لما نصعد الجبل ماذا يحدث للضغط : ينخفض ام يرتفع
4. ليش الناس لما تصعد الجبل تشعر بضيق في التنفس
5. طيب ماذا يحدث لدرجة الغليان عندما ينخفض الضغط؟؟
6. هل يغلي ألماء عند درجة حرارة ٥٠ درجة
7. طيب اذا يغلي عند خمسين ، كم درجة حرارة البخار
8. انت اخترتي اجابة ان درجة بخار الماء ١٢٠، ممكن تعطيني فكرة ليش اخترتي الاجابة هاذي، بالتفصيل (الممل)
9. ليش نحس ان درجة حرارة البخار اكبر من درجة حرارة الماء المغلي؟
10. ليش في المنحنى تبع تحولات الماء يقول ان درجة حرارة البخار ١٢٠ درجة؟
11. اذا كان الماء يغلي عند درجة ٧٥ درجة (لأي سبب من الأسباب مثل الارتفاع) كم درجة حرارة البخار في دي الحالة؟
12. الطاقة الحرارية بوشو تقاس؟

Appendix B Ethic approval

This appendix contains the Official permission that was granted from Curtin University, Office of Research and Development to conduct this study in the eastern province of Saudi (approval number being SMEC-09-140). Permission was also granted from the Higher Education Ministry in Riyadh, Saudi (approval number being 8821934) and from the Ministry of Education in Dammam, Saudi (approval number being 351963211). All test materials for this study has been reviewed by the Department of Planning and Development in the Western Province of Saudi.

Curtin University

Memorandum

To	Asmahan Al Safwan, SMEC
From	Mun Yin Cheong, Form C Ethics Co-ordinator Faculty of Science and Engineering
Subject	Protocol Approval **SMEC-09-14**
Date	4 March 2014
Copy	David Treagust, SMEC

Office of Research and Development

Human Research Ethics Committee

Telephone 9266 2784
Facsimile 9266 3793
Email hrec@curtin.edu.au

Thank you for your "Form C Application for Approval of Research with Low Risk (Ethical Requirements)" for the project titled *"Saudi Female High School Students' Understanding of Thermal Concepts"*. On behalf of the Human Research Ethics Committee, I am authorised to inform you that the project is approved.

Approval of this project is for a period of 4 years **27th February 2014** to **26th February 2018**.

Your approval has the following conditions:

(i) Annual progress reports on the project must be submitted to the Ethics Office.

(ii) It is your responsibility, as the researcher, to meet the conditions outlined above and to retain the necessary records demonstrating that these have been completed.

The approval number for your project is **SMEC-09-14**. Please quote this number in any future correspondence. If at any time during the approval term changes/amendments occur, or if a serious or unexpected adverse event occurs, please advise me immediately.

Regards,

Mun Yin

MUN YIN CHEONG
Form C Ethics Co-ordinator
Faculty of Science and Engineering

Please Note: The following standard statement must be included in the information sheet to participants:
This study has been approved under Curtin University's process for lower-risk Studies (Approval Number xxxx). This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18-5.1.21).
For further information on this study contact the researchers named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au.

Standard conditions of ethics approval

These standard conditions apply to all research approved by the Curtin University Human Research Ethics Committee. It is the responsibility of each researcher named on the application to ensure these conditions are met.

1. **Compliance.** Conduct your research in accordance with the application as it has been approved and keep appropriate records.
    a. **Monitoring** - Assist the Committee to monitor the conduct of the approved research by completing promptly and returning all project review forms that are sent to you.
    b. **Annual report** - Submit an annual report on or before the anniversary of the approval.
    c. **Extensions** - If you are likely to need more time to conduct your research than is already approved, complete a new application six weeks before the current approval expires.
    d. **Changes to protocol** - Any changes to the protocol are to be approved by the Committee before being implemented.
    e. **Changes to researcher details** - Advise the Committee of any changes in the contact details of the researchers involved in the approved study.
    f. **Discontinuation** - You must inform the Committee, giving reasons, if the research is not conducted or is discontinued before the expected completion date.
    g. **Closure** - Submit a final report when the research is completed. Include details of when data will be destroyed, and how, or if any future use is planned for the data.
    h. **Candidacy** - If you are a Higher Degree by Research student, data collection must not begin before your Application for Candidacy is approved by your Faculty Graduate Studies Committee.
2. **Adverse events.** Consider what might constitute an adverse event and what actions may be needed if an adverse event occurs. Follow the procedures for reporting and addressing adverse events (http://research.curtin.edu.au/guides/adverse.cfm).Where appropriate, provide an adverse events protocol. The following are examples of adverse events:
    a. Complaints
    b. Harm to participants. This includes physical, emotional, psychological, economic, legal, social and cultural harm (NS Section 2)
    c. Loss of data or breaches of data security
    d. Legal challenges to the research
3. **Data management plan.** Have a Data Management Plan consistent with the University's recordkeeping policy. This will include such things as how the data are to be stored, for how long, and who has authorised access.
4. **Publication.** Where practicable, ensure the results of the research are made available to participants in a way that is timely and clear (NS 1.5). Unless prohibited from doing so by contractual obligations, ensure the results of the research are published in a manner that will allow public scrutiny (NS 1.3, d). Inform the Committee of any constraints on publication.
5. **Police checks and other clearances.** All necessary clearances, such as Working with Children Checks, first aid certificates and vaccination certificates, must be obtained before entering a site to conduct research.
6. **Participant information.** All information for participants must be approved by the HREC before being given to the participants or made available to the public.
    a. **University logo.** All participant information and consent forms must contain the Curtin University logo and University contact details for the researchers. Private contact details should not be used.
    b. **Standard statement.** All participant information forms must contain the HREC standard statement.
    This study has been approved under Curtin University's process for lower-risk Studies (Approval Number xxxx). This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18-5.1.21).
    For further information on this study contact the researchers named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au.
    c. **Plain language.** All participant information must be in plain language that will be easily understood by the participants.

Please direct all communication through the your Form C Ethics Co-ordinator.

* Form C Coordinator cannot not approve amendment request, these must be approved by a Form C reviewer.

Appendix C Thermal Concept Evaluation (TCE)

This appendix contains the main instrument in this study that used to measure Saudi high school students understanding of thermal concepts in its two forms: the English and the Arabic one, as well as the bubble sheet that has been provided to students to use as answer sheet. The English version of Thermal Concept Evaluation (TCE) has been taken from (Yeo & Zadnik, 2001).

Thermal Concept Evaluation (English version)[11]

Appendix I
Thermal Concept Evaluation

- This questionnaire is about your understandings about *heat* and *temperature*.
- To help visualize each situation, think of a group of friends in a kitchen or cafeteria. Imagine that they are observant and interested in understanding common phenomena. They explain their ideas to one another.
- For each question, choose the answer that is *closest to your understanding*.
- Be careful to mark the alternative you want to. Some questions have five choices.

1. What is the most likely temperature of ice cubes stored in a refrigerator's freezer compartment?
   a. –10°C
   b. 0°C
   c. 5°C
   d. It depends on the size of the ice cubes.

2. Ken takes six ice cubes from the freezer and puts four of them into a glass of water. He leaves two on the countertop. He stirs and stirs until the ice cubes are much smaller and have stopped melting. What is the most likely temperature of the water at this stage?
   a. –10°C c. 5°C
   b. 0°C d. 10°C

3. The ice cubes Ken left on the counter have almost melted and are lying in a puddle of water. What is the most likely temperature of these smaller ice cubes?
   a. –10°C c. 5°C
   b. 0°C d. 10°C

4. On the stove is a kettle full of water. The water has started to boil rapidly. The most likely temperature of the water is about:
   a. 88°C
   b. 98°C
   c. 110°C
   d. None of the above answers could be right.

5. Five minutes later, the water in the kettle is still boiling. The most likely temperature of the water now is about:
   a. 88°C c. 110°C
   b. 98°C d. 120°C

6. What do you think is the temperature of the steam above the boiling water in the kettle?
   a. 88°C c. 110°C
   b. 98°C d. 120°C

7. Lee takes two cups of water at 40°C and mixes them with one cup of water at 10°C. What is the most likely temperature of the mixture?
   a. 20°C c. 30°C
   b. 25°C d. 50°C

8. Jim believes he must use boiling water to make a cup of tea. He tells his friends: "I couldn't make tea if I was camping on a high mountain because water doesn't boil at high altitudes."
   a. Joy says: "Yes it does, but the boiling water is just not as hot as it is here."
   b. Tay says: "That's not true. Water always boils at the same temperature."
   c. Lou says: "The boiling point of the water decreases, but the water itself is still at 100 degrees."
   d. Mai says: "I agree with Jim. The water never gets to its boiling point."
   Who do you agree with?

9. Sam takes a can of cola and a plastic bottle of cola from the refrigerator, where they have been overnight. He quickly puts a thermometer in the cola in the can. The temperature is 7°C. What are the most likely temperatures of the plastic bottle and cola it holds?
   a. They are both less than 7°C.
   b. They are both equal to 7°C.
   c. They are both greater than 7°C.
   d. The cola is at 7°C but the bottle is greater than 7°C.
   e. It depends on the amount of cola and/or the size of the bottle.

10. A few minutes later, Ned picks up the cola can and then tells everyone that the countertop underneath it feels colder than the rest of the counter.
   a. Jon says: "The cold has been transferred from the cola to the counter."
   b. Rob says: "There is no energy left in the counter beneath the can."
   c. Sue says: "Some heat has been transferred from the counter to the cola."
   d. Eli says: "The can causes heat beneath the can to move away through the countertop."
   Whose explanation do you think is best?

11. Pam asks one group of friends: "If I put 100 grams of ice at 0°C and 100 grams of water at 0°C into a freezer, which one will eventually lose the greatest amount of heat?
   a. Cat says: "The 100 grams of ice."
   b. Ben says: "The 100 grams of water."
   c. Nic says: "Neither because they both contain the same amount of heat."
   d. Matt says: "There's no answer, because ice doesn't contain any heat."
   e. Jed says: "There's no answer, because you can't get water at 0°C."
   Which of her friends do you most agree with?

12. Mel is boiling water in a saucepan on the stovetop. What do you think is in the bubbles that form in the boiling water? Mostly:
   a. Air
   b. Oxygen and hydrogen gas

[11] "Reproduced from Yeo and Zadnik (2001), with the permission of the American Association of Physics Teachers."

Thermal Concept Evaluation (English version)[11]

c. Water vapor
d. There's nothing in the bubbles.

13. After cooking some eggs in the boiling water, Mel cools the eggs by putting them into a bowl of cold water. Which of the following explains the cooling process?

a. Temperature is transferred from the eggs to the water.
b. Cold moves from the water into the eggs.
c. Hot objects naturally cool down.
d. Energy is transferred from the eggs to the water.

14. Jan announces that she does not like sitting on the metal chairs in the room because "they are colder than the plastic ones."

a. Jim agrees and says: "They are colder because metal is naturally colder than plastic."
b. Kip says: "They are not colder, they are at the same temperature."
c. Lou says: "They are not colder, the metal ones just feel colder because they are heavier."
d. Mai says: "They are colder because metal has less heat to lose than plastic."

Who do you think is right?

15. A group is listening to the weather forecast on a radio. They hear: *"... tonight it will be a chilly 5°C, colder than the 10°C it was last night."*

a. Jen says: "That means it will be twice as cold tonight as it was last night."
b. Ali says: "That's not right. 5°C is not twice as cold as 10°C."
c. Raj says: "It's partly right, but she should have said that 10°C is twice as warm as 5°C."
d. Guy says: "It's partly right, but she should have said that 5°C is half as cold as 10°C."

Whose statement do you most agree with?

16. Kim takes a metal ruler and a wooden ruler from his pencil case. He announces that the metal one feels colder than the wooden one. What is your preferred explanation?

a. Metal conducts energy away from his hand more rapidly than wood.
b. Wood is a naturally warmer substance than metal.
c. The wooden ruler contains more heat than the metal ruler.
d. Metals are better heat radiators than wood.
e. Cold flows more readily from a metal.

17. Amy took two glass bottles containing water at 20°C and wrapped them in washcloths. One of the washcloths was wet and the other was dry. 20 minutes later, she measured the water temperature in each. The water in the bottle with the wet washcloth was 18°C, the water in the bottle with the dry washcloth was 22°C. The most likely room temperature during this experiment was:

a. 26°C c. 20°C
b. 21°C d. 18°C

18. Dan simultaneously picks up two cartons of chocolate milk, a cold one from the *refrigerator* and a warm one that has been sitting on the *countertop* for some time. Why do you think the carton from the refrigerator ***feels*** colder than the one from the countertop? Compared with the warm carton, the cold carton —

a. contains more cold.
b. contains less heat.
c. is a poorer heat conductor.
d. conducts heat more rapidly from Dan's hand.
e. conducts cold more rapidly to Dan's hand.

19. Ron reckons his mother cooks soup in a pressure cooker because it cooks faster than in a normal saucepan but he doesn't know why. [Pressure cookers have a sealed lid so that the pressure inside rises well above atmospheric pressure.]

a. Emi says: "It's because the pressure causes water to boil above 100°C."
b. Col says: "It's because the high pressure generates extra heat."
c. Fay says: "It's because the steam is at a higher temperature than the boiling soup."
d. Tom says: "It's because pressure cookers spread the heat more evenly through the food."

Which person do you most agree with?

20. Pat believes her Dad cooks cakes on the top shelf inside the electric oven because it is hotter at the top than at the bottom.

a. Pam says that it's hotter at the top because heat rises.
b. Sam says that it is hotter because metal trays concentrate the heat.
c. Ray says it's hotter at the top because the hotter the air the less dense it is.
d. Tim disagrees with them all and says that it's not possible to be hotter at the top.

Which person do you think is right?

21. Bev is reading a multiple-choice question from a textbook: "Sweating cools you down because the sweat lying on your skin:

a. wets the surface, and wet surfaces draw more heat out than dry surfaces."
b. drains heat from the pores and spreads it out over the surface of the skin."
c. is the same temperature as your skin but is evaporating and so is carrying heat away."
d. is slightly cooler than your skin because of evaporation and so heat is transferred from your skin to the sweat."

Which answer would you tell her to select?

22. When Zack uses a bicycle pump to pump up his bike tires, he notices that the pump becomes quite hot. Which explanation below seems to be the best one?

a. Energy has been transferred to the pump.
b. Temperature has been transferred to the pump.
c. Heat flows from his hands to the pump.
d. The metal in the pump causes the temperature to rise.

Thermal Concept Evaluation (English version)[11]

23. Why do we wear sweaters in cold weather?
    a. To keep cold out.
    b. To generate heat.
    c. To reduce heat loss.
    d. All three of the above reasons are correct.

24. Vic takes some Popsicles from the freezer, where he had placed them the day before, and tells everyone that the wooden sticks are at a higher temperature than the ice part.
    a. Deb says: "You're right because the wooden sticks don't get as cold as ice does."
    b. Ian says: "You're right because ice contains more cold than wood does."
    c. Ross says: "You're wrong, they only feel different because the sticks contain more heat."
    d. Ann says: "I think they are at the same temperature because they are together."

   Which person do you most agree with?

25. Gay is describing a TV segment she saw the night before: "I saw physicists make super-conductor magnets, which were at a temperature of −260°C."
    a. Joe doubts this: "You must have made a mistake. You can't have a temperature as low as that."
    b. Kay disagrees: "Yes you can. There's no limit on the lowest temperature."
    c. Leo believes he is right: "I think the magnet was near the lowest temperature possible."
    d. Gay is not sure: "I think super-conductors are good heat conductors so you can't cool them to such a low temperature."

   Who do you think is right?

26. Four students were discussing things they did as kids. The following conversation was heard: Ami: "I used to wrap my dolls in blankets but could never understand why they didn't warm up."
    a. Nick replied: "It's because the blankets you used were probably poor insulators."
    b. Lyn replied: "It's because the blankets you used were probably poor conductors."
    c. Jay replied: "It's because the dolls were made of material which did not hold heat well."
    d. Kev replied: "It's because the dolls were made of material which took a long time to warm up."
    e. Joy replied: "You're all wrong."

   Who do you agree with?

Appendix II

Notes on Statistical Procedures

Effect size = $|X_2 - X_1|/\sigma_1$ where X = mean, σ = standard deviation.

Use of this form assumes equal variances (σ^2). If the variances are unequal, a "pooled" variance can be determined using the equation:

$$\sigma^2 = [\,\sigma_1^2(N_1 - 1) + \sigma_2^2(N_2 - 1)] \,/\, [N_1 + N_2 - 2].$$

The average normalized gain was calculated using the equation:

$$g = [X_{post} - X_{pre}] \,/\, [100 - X_{pre}].$$

Index of item difficulty (E) is defined as:

$$E = \frac{\textit{(number correct in upper 27\%) + (number correct in lower 27\%)}}{\textit{total number in upper and lower groups}}.$$

E is normally expressed as a percentage; the higher the percentage, the easier the item.

Index of item discrimination (D) is defined as:

$$D = \frac{\textit{(number correct in upper 27\%) − (number correct in lower 27\%)}}{\textit{number in upper (or lower) group}}.$$

An index of discrimination facilitates differentiation between high- and low-achieving students. D is normally expressed as a quotient. The higher the quotient, the greater the difference between upper and lower group responses to the item, with more of the upper group answering correctly.

The upper and lower 27% of students were on the basis of their ranked test scores. The value 27% is an optimum value maximizing separation between the high and low groups (resulting in small group numbers) while having sufficient numbers in either group to produce reliable statistics.

Thermal Concept Evaluation (Arabic version)

This appendix contains the Arabic version of the main instrument TCE of Yeo and Zadnik (2001) as well as the student version.

استمارة تقييم مدى استيعاب الطالب لمفهومي الحرارة و درجة الحرارة
للصف الثاني الثانوي علمي

ملحوظات:

- هذة استمارة تقييم مدى استيعاب الطالب لمفهومي الحرارة و درجة الحرارة. وهي ترجمة للتقييم الاصلي مع بعض التصرف*.
- افهم الاسئلة بشكل جيد – تصور مجموعه من الاصدقاء مجتمعين في المطبخ في منزل احدهم ولديهم فضول لفهم الظواهر الفيزيائية التي تحدث امامهم – فيتبادلون الاراء فيما بينهم حول هذه الظواهر.
- بالنسبة لك – حاول ان تختار الاجابة الاقرب الى فهمك.
- بعض الاسئلة تحتاج الى تركيز اكبر قبل الاجابة . وبعض الاسئلة قد تكون مرتبطة بالسؤال الذي يسبقها .

1. مجموعة من مكعبات الثلج موجودة في الفريزر. ما هي درجة الحرارة المتوقعة لمكعبات الثلج ؟
   a) −10°C b) 0°C
   c) 5°C d) درجة حرارة مكعبات الثلج تعتمد على حجمها .

2. أخذ كريم منها 6 مكعبات من الثلج ، ووضع 4 منها في كاس ماء من الصنبور، بينما ترك مكعبين على طاولة المطبخ . قام كريم بتحريك مكعبات الثلج الموجودة في كاس الماء باستمرار الى ان توقفت مكعبات الثلج عن الذوبان واصبح حجمها اصغر بكثير من حجمها الاصلي. ما هي درجة الحرارة المتوقعة للماء في هذه المرحلة ؟
   a) −10°C b) 0°C
   c) 5°C d) 10°C

3. بالنسبة لمكعبي الثلج اللذين تركهما كريم على طاولة المطبخ ، تقريبا ذابا ولم يتبق الا جزء صغير منهما في بقعة من الماء. ما هي درجة الحرارة المتوقعة لهذه المكعبات الصغيرة في هذه الحالة ؟
   a) −10°C b) 0°C
   c) 5°C d) 10°C

4. أبريق شاي يحوي ماء موضوع على موقد . بدأ الماء بالغليان بشكل منتظم. ما هي درجة الحرارة المتوقعة للماء في هذه المرحلة ؟
   a) 88°C b) 98°C
   c) 110°C d) جميع الاجابات السابقة خاطئة.

5. خمس دقائق مضت ، والماء لا زال يغلي داخل الابريق . ما هي درجة الحرارة المتوقعة للماء في هذه المرحلة ؟
   a) 88°C b) 98°C
   c) 110°C d) 120°C

6. برأيك : ما هي درجة الحرارة المتوقعة لبخار الماء المتصاعد من الابريق في هذه المرحلة ؟
   a) 88°C b) 98°C
   c) 110°C d) 120°C

7. أخذ لؤي كوبين من الماء درجة حرارتهما 40°C ، ومزجهما مع كوب من الماء درجة حرارته 10°C . ما هي درجة الحرارة المتوقعة للخليط ؟
   a) 20°C b) 25°C .
   c) 30°C d) 50°C

8. جميل الذي يعتقد انه يحتاج الى ماء مغلي لصنع كوبا من الشاي يتذكر قائلا: عندما كنت في مخيم الكشافة ، لم اتمكن من صنع الشاي هناك ، لان الماء لا يغلي في المرتفعات والجبال الشاهقة الارتفاع. تمعن في الاجابات التالية ، مع من تتفق ؟
   a) جاسم قال : لا ، انه يغلي . ولكن الفرق ان الماء المغلي هناك ليس حارا كما هو هنا .
   b) طلال قال : غير صحيح ، لان الماء دائما يغلي عند نفس درجة الحرارة .
   c) الياس قال : نقطة الغليان تنخفض . ولكن درجة حرارة الماء نفسه هي 100 درجة مئوية.
   d) مؤيد قال : انا اتفق مع جميل . الماء لا يصل ابدا الى نقطة غليانه.

9. تناول سامي علبتين من المشروبات الغازية (احداهما معدنية والاخرى بلاستيكية) كانتا موضوعتين في الثلاجة طوال الليل ، وقام مباشرة بوضع ترمومتر في العلبة المعدنية، فكانت القراءة 7°C . برايك : ما هي درجة الحرارة المتوقعة للعلبة البلاستيكية والمشروب الغازي الموجود فيها ؟
   a) كلاهما عند درجة حرارة اقل من 7°C .
   b) كلاهما عند درجة حرارة تساوي 7°C .
   c) كلاهما عند درجة حرارة اكبر من 7°C .
   d) المشروب الغازي عند درجة حرارة 7°C ولكن علبته البلاستيكية عند درجة حرارة اكبر من 7°C .
   e) ذلك يعتمد على كمية المشروب الغازي و/ او حجم العلبة البلاستيكية.

10. بعد عدة دقائق ، رفع نادر علبة المشروب الغازي المعدنية من على طاولة المطبخ واخبر الجميع ان الجزء من الطاولة تحت العلبة المعدنية ابرد من بقية الطاولة. تمعن في الاجابات التالية وحدد الاجابة الفضلى ؟
    a) جابر قال : انتقلت البرودة من المشروب الغازي الى الطاولة.
    b) ربيع قال : لم يتبق اي طاقة في الطاولة تحت علبة المشروب الغازي.
    c) صالح قال : بعض الحرارة انتقلت من الطاولة الى علبة المشروب الغازي .
    d) علي قال : علبة المشروب المعدنية تسببت في طرد الحرارة بعيدا من تحتها خلال الطاولة.

11. سأل باسم مجموعة من اصدقائه : اذا وضعنا 100 جم من الثلج و 100 جم من الماء ، درجة حرارتهما صفر درجة مئوية في الفريزر . في نهاية المطاف ، من منهما سيفقد مقدار اكبر من كمية الحرارة ؟ تمعن في الاجابات التالية ، مع منْ تتفق ؟

Thermal Concept Evaluation (Arabic version)

استمارة تقييم مدى استيعاب الطالب لمفهومي الحرارة و درجة الحرارة
للصف الثاني الثانوي علمي

a) كرم قال : المئة جرام من الثلج .
b) بشار قال : المئة جرام من الماء .
c) نديم قال : كلاهما سيفقد نفس المقدار لانهما يحتويان على نفس كمية الحرارة.
d) جواد قال : لا توجد اجابة . لان الثلج لا يحوي اي كمية حرارة.
e) مازن قال : لا توجد اجابة . لانه لايمكن الحصول على ماء في درجة حرارة صفر درجة مئوية .

12. يقوم مصطفى بغلي ماء في قدر على الموقد . برايك : في الغالب ماذا يوجد في داخل الفقاعات الموجودة في الماء المغلي؟
a) هواء. b) غازي الاكسجين والهيدروجين.
c) بخار الماء. d) لاشئ في الفقاعات.

13. بعد سلقه البيض في ماء مغلي ، قام مجتبى بوضع البيض في قدر يحوي ماء بارد لجعلها تبرد بسرعة . اي من التفسيرات التالية يوضح عملية التبريد ؟
a) انتقلت درجة الحرارة من البيض الى الماء.
b) انتقلت البرودة من الماء الى البيض .
c) الاجسام الحارة بطبيعتها تبرد تلقائيا.
d) انتقلت الطاقة من البيض الى الماء.

14. جهاد اخبر الجميع انه لا يفضل الجلوس على الكراسي المعدنية في الغرفة " انها ابرد من مثيلتها البلاستيكية ". تمعن في الاجابات التالية، برايك: من هو على صواب ؟
a) جميل يتفق معه : انها ابرد . لان المعدن بطبيعته ابرد من البلاستك.
b) سمير قال : انها ليست ابرد ! كلهم لهم نفس درجة الحرارة.
c) لطفي قال : انها ليست ابرد ! لكن الكراسي المعدنية تبدو ابرد لانها اثقل .
d) ماجد قال : انها ابرد ! لان المعدن يحتوي كمية اقل من الحرارة ليفقدها مقارنة بالبلاستيك.

15. مجموعة اصدقاء يستمعون الى النشرة الجوية من خلال الراديو. المذيعة: "ستكون ليلة قارصة البرودة مع درجة حرارة 5°C ، أبرد من الليلة الماضية حيث كانت 10°C ".
تمعن في الاجابات التالية ، مع من تتفق ؟
a) جواد قال : ذلك يعني ان البرودة هذه الليلة ستكون ضعف برودة الليلة الماضية .
b) محمد قال : هذا غير صحيح . البرودة عند 5°C ليست ضعف البرودة عند 10°C
c) رائد قال : المذيعة جزئيا على صواب. ولكن يفترض بها ان تقول ان الـ 10°C ادفأ بمقدار الضعف من الـ 5°C .
d) جمال قال : المذيعة جزئيا على صواب. ولكن يفترض بها ان تقول الـ 5°C أبرد بمقدار النصف من الـ 10°C

16. اخرج ضياء مسطرتين من مقلمته ، احداهما معدنية والاخرى خشبية واخبر الجميع ان المسطرة المعدنية تبدو ابرد من مثيلها الخشبية . تمعن في الاجابات التالية ، أيها تفضل ؟
a) المعدن يطرد الطاقة من يده بعيدا بشكل اسرع من الخشب.
b) الخشب مادة بطبيعتها أدفأ من المعدن.
c) المسطرة الخشبية تحوي كمية حرارة اكبر من مثيلتها المعدنية.
d) المعدن يعتبر مشع جيد للحرارة .
e) المعدن يعتبر مشع جيد للبرودة.

17. أخذ أيمن زجاجتين A,B تحويان ماء عند درجة حرارة 20°C وقام بلف الزجاجة A بمنشفة رطبة ، و الزجاجة B بمنشفة جافة. بعد مرور 20 دقيقة ، قام بقياس درجة حرارة الماء في كلتاهما. درجة حرارة الماء الموجود في الزجاجة A كانت 18°C بينما كانت درجة حرارة الماء في الزجاجة B هي 22°C . ماهي درجة حرارة الغرفة المتوقعة حين اجراء التجربة؟
a) 26°C b) 21°C
c) 20°C d) 18°C

18. أخذ وهب علبتين كرتون حليب الشوكلاته في نفس الوقت، أحداهما باردة من الثلاجة و الاخرى دافئة من على طاولة المطبخ. برأيك لماذا العلبة المأخوذة من الثلاجة تبدو أبرد من الاخرى؟ مقارنة بالعلبة الدافئة ، فإن العلبة الباردة :
a) تحوي برودة اكثر .
b) تحوي كمية حرارة اقل .
c) تعتبر موصل ردئ للحرارة.
d) تمتص الحرارة بشكل اسرع من يد وهب.
e) توصل البرودة بشكل اسرع الى يد وهب.

19. يعتقد رائد ان أمه تطهي الحساء في طنجرة الضغط لانها اسرع من الطناجر العادية . ولكنه لا يعرف السبب وراء ذلك. تمعن في الاجابات التالية ، مع من تتفق ؟ ملحوظة:(طناجر الضغط يكون لها غطاء محكم الاغلاق حتى يتسنى للضغط في الداخل بالارتفاع أعلى بكثير من الضغط الجوي).
a) احمد قال : ذلك لان الضغط يتسبب في ان الماء يغلي الى درجات حرارة اعلى من 100°C .
b) حسن قال :ذلك لان الضغط العالي يولد كمية حرارة اكبر.
c) فادي قال : ذلك لان درجة حرارة البخار اكبر من درجة حرارة الحساء المغلي.
d) طاهر يقول : ذلك لان طنجرة الضغط توزع الحرارة خلال الطعام بشكل متساو

20. بهاء يعتقد ان اباه يطهي الكيك في الرف العلوي للفرن الكهربائي، لانها اكثر حرارة في الاعلى منها في الاسفل . تمعن في الاجابات التالية ، برأيك : أيهم على صواب ؟
a) تيسير قال : انها اكثر حرارة في الاعلى ، لان الحرارة تتحرك من الاسفل الى الاعلى .
b) امجد قال : انها اكثر حرارة في الاعلى ، لان الرف المعدني يعمل على تركيز الحرارة .

Thermal Concept Evaluation (Arabic version)

استمارة تقييم مدى استيعاب الطلب لمفهومي الحرارة و درجة الحرارة
للصف الثاني الثانوي علمي

c) سعيد قال : انها اكثر حرارة في الاعلى ، لانه الهواء عندما يسخن تقل كثافته ويرتفع للاعلى.
d) فارس يختلف معهم جميعا . فارس يقول : لا يمكن ان يكون الجزء العلوي من الفرن اكثر حرارة من بقية الفرن.

21. أسامة يقرأ سؤال متعددة الاختيارات في كتاب الفيزياء. ساعده في اختيار الاجابة الصحيحة لهذا السؤال: " التعرق يعمل على تبريد الجسم لان العرق الموجود على الجلد ..... "
a) يبلل سطح الجلد . فالاسطح المبللة تطرد الحرارة الخارج اسرع من السطوح الجافة.
b) يصرف الحرارة عبر المسام وينشرها بعيدا من خلال سطح الجلد.
c) له درجة حرارة مساوية لدرجة حرارة الجسم ، ولكنه يتبخر حاملا معه الحرارة بعيدا .
d) له درجة حرارة اقل قليلا من درجة حرارة الجسم ، حيث تنتقل كمية من الحرارة من الجسم الى العرق فيتبخر .

22. عندما استخدم زكريا المنفاخ لينفخ اطارات دراجته ، لاحظ ان المنفاخ اصبح حارا. تمعن في التعليلات التالية ، برأيك : ما هي افضل اجابة ؟
a) انتقلت الطاقة الى المنفاخ .
b) انتقلت درجة الحرارة الى المنفاخ .
c) انتقلت كمية من الحرارة من يده الى المنفاخ .
d) تسبب الجزء المعدني في المنفاخ في ارتفاع درجة الحرارة.

23. لماذا نلبس المعاطف في الاجواء الباردة ؟
a) لابقاء البرودة خارجا.
b) لتوليد الحرارة .
c) لتقليل كمية الحرارة المفقودة.
d) جميع ماسبق.

24. استخرج محسن مصاصة مثلجة من الفريزر ، كان قد وضعها في الامس . محسن اخبر الجميع ان درجة حرارة العصا الخشبية أعلى من درجة حرارة الجزء المثلج من المصاصة . تمعن في الاجابات التالية ، مع من تتفق ؟
a) مؤيد قال : انك على صواب . العصا الخشبية لا تصبح بنفس برودة الجزء المثلج .
b) قاسم قال : انك على صواب . لان الجزء المثلج يحوي برودة اكثر من العصا الخشبية.
c) طارق قال : انك مخطئ . هما يبدوان مختلفين لان العصا الخشبية تحوي كمية حرارة اكثر .
d) يوسف قال : انا اعتقد ان لهما نفس درجة الحرارة لانهما ملتصقان ببعض .

25. هاني يصف عرض تلفزيوني شاهده الليلة الماضية :" تمكن الفيزيائيين من صنع مغناطيس فائق الموصلية ، عند درجة حرارة −260°C ". تمعن في الاجابات التالية ، مع من تتفق ؟
a) معتز شكك في ذلك : لابد انك مخطئ . لا يمكن الحصول على درجة حرارة منخفضة الى هذا الحد !
b) عادل أجاب معترضا : نعم يمكن ذلك . لا يوجد حد ادنى لدرجات الحرارة المنخفضة .
c) زهير يعتقد ان هاني مصيب : أعتقد ان المغناطيس كان عند أدنى درجة حرارة ممكنه .
d) إبراهيم قال : انا اعتقد ان الموصلات فائقة الموصلية ، هي ايضا موصلة جيدة للحرارة . لذلك لا يمكن تبريدها الى مثل ذلك درجة الحرارة المنخفضة.

26. قال حسام : اختي الصغيرة دائما تلف لعبتها بالبطانية . ولكن مالا افهمه : لماذا هذه الدمية لا تصبح دافئة ؟
a) راجح قال : احتمال ان البطانية التي استخدمتها لم تكن عازلة جيدة للحرارة.
b) سجاد قال : احتمال ان البطانية التي استخدمتها لم تكن موصلة جيدة للحرارة .
c) عصام قال : لان الدمى مصنوعة من مادة لا تحتفظ بالحرارة جيدا .
e) ماهر قال : لان الدمى مصنوعة من مادة تحتاج الى وقت اطول لتدفأ .
f) حسين قال : كلكم مخطئين.

Thermal Concept Evaluation (Student's version)

استمارة تقييم مدى استيعاب الافراد لمفهومي الحرارة ودرجة الحرارة

<u>ملحوظات:</u>

- هذه استمارة تقييم مدى استيعاب الطالب لمفهومي الحرارة ودرجة الحرارة. وهي ترجمة للتقيم الأصلي مع بعض التصرف*.
- لفهم الأسئلة بشكل جيد – تصوري مجموعه من الأصدقاء مجتمعين في المطبخ في منزل أحدهم ولديهم فضول لفهم الظواهر الفيزيائية التي تحدث أمامهم – فيتبادلون الآراء فيما بينهم حول هذه الظواهر.
- بعض الأسئلة تحتاج إلى تركيز أكبر قبل الإجابة. وبعض الأسئلة قد تكون مرتبطة بالسؤال الذي يسبقها.
- الإجابة على الأسئلة قد لا تعني لك الكثير ولكن هي مهمة للباحثين من اجل تطوير المناهج وطرق التدريس.
- أجابتك لن تؤثر على مستواك أو علاقتك بمعلمتك كما أن إجاباتك ستبقى سرية ولن تستخدم إلا لأغراض بحثية بحتة.
- بالنسبة لك:
  - حاولي أن تختاري الإجابة الأقرب إلى فهمك بوضع دائرة حول الإجابة.
  - حددي مدى تأكدك من الإجابة.
  - حددي ما إذا كنتي تعتقدي أن إجابتك معقولة أو لا.
  - حددي مصدر إجاباتك في نهاية الاستبيان.

<u>توضيح:</u>

معقولية الإجابة: بعض الأحيان نحن متأكدين من فقرة معينة أنها هي الصحيحة ولكنها بالنسبة لنا غير معقولة لأنها تخالف تجربتنا الشخصية:

مثال: اختر الإجابة الصحيحة:

الحوت: ☐ من الطيور ☐ من الحشرات ☐ من الزواحف. ☐ ليس من الأسماك.

نحن نعلم أن الإجابات الثلاثة الأولى خاطئة 100%. ولكن ماذا عن الإجابة الرابعة؟ أنها الإجابة الوحيدة المحتملة ولكنها غير معقولة لأنها تخالف ما نعرفه أن الحوت كالسمك يسبح في البحر وله شكل السمك ولكن العلماء تصنفه ضمن الثدييات.

السؤال	مدى التأكد / مدى المعقولية
1. مجموعة من مكعبات الثلج موجودة في الفريزر. ما هي درجة الحرارة المتوقعة لمكعبات الثلج؟ a) −10°C　b) 0°C c) 5°C　d) درجة حرارة مكعبات الثلج تعتمد على حجمها	متأكد جدا 7 6 5 4 3 2 1 تخمين معقول جدا 7 6 5 4 3 2 1 غير معقول
2. أخذ كريم منها 6 مكعبات من الثلج، ووضع 4 منها في كاس ماء من الصنبور، بينما ترك مكعبين على طاولة المطبخ. قام كريم بتحريك مكعبات الثلج الموجودة في كاس الماء باستمرار إلى أن توقفت مكعبات الثلج عن الذوبان وأصبح حجمها أصغر بكثير من حجمها الأصلي. ما هي درجة الحرارة المتوقعة للماء في هذه المرحلة؟ a) −10°C　b) 0°C c) 5°C　d) 10°C	متأكد جدا 7 6 5 4 3 2 1 تخمين معقول جدا 7 6 5 4 3 2 1 غير معقول
3. بالنسبة لمكعبي الثلج اللذين تركهما كريم على طاولة المطبخ، تقريبا ذابا ولم يتبق إلا جزء صغير منهما في بقعة من الماء. ما هي درجة الحرارة المتوقعة لهذه المكعبات الصغيرة في هذه الحالة؟ a) −10°C　b) 0°C c) 5°C　d) 10°C	متأكد جدا 7 6 5 4 3 2 1 تخمين معقول جدا 7 6 5 4 3 2 1 غير معقول
4. أبريق شاي يحوي ماء موضوع على موقد. بدأ الماء بالغليان بشكل مطرد. ما هي درجة الحرارة المتوقعة للماء في هذه المرحلة؟ a) C°88　b) C°98 c) C°110　d) جميع الإجابات السابقة خاطئة.	متأكد جدا 7 6 5 4 3 2 1 تخمين معقول جدا 7 6 5 4 3 2 1 غير معقول
5. خمس دقائق مضت، والماء لا زال يغلي داخل الأبريق. ما هي درجة الحرارة المتوقعة للماء في هذه المرحلة؟ a) 88°C　b) 98°C c) 110°C　d) 120°C	متأكد جدا 7 6 5 4 3 2 1 تخمين معقول جدا 7 6 5 4 3 2 1 غير معقول
6. برأيك: ما هي درجة الحرارة المتوقعة لبخار الماء المتصاعد من الأبريق في هذه المرحلة؟ a) C°88　b) C°98 c) C°110　d) C°120	متأكد جدا 7 6 5 4 3 2 1 تخمين معقول جدا 7 6 5 4 3 2 1 غير معقول
7. أخذ لؤي كوبين من الماء درجة حرارتها 40°C ، ومزجهما مع كوب من الماء درجة حرارته 10°C . ما هي درجة الحرارة المتوقعة للخليط؟ a) 20°C　b) 25°C . c) 30°C　d) 50°C	متأكد جدا 7 6 5 4 3 2 1 تخمين معقول جدا 7 6 5 4 3 2 1 غير معقول

Thermal Concept Evaluation (Student's version)

استمارة تقييم مدى استيعاب الطالب لمفهومي الحرارة و درجة الحرارة
للصف الثاني الثانوي علمي

c) سعيد قال : انها اكثر حرارة في الاعلى ، لانه الهواء عندما يسخن تقل كثافته ويرتفع للاعلى.
d) فارس يختلف معهم جميعا . فارس يقول : لا يمكن ان يكون الجزء العلوي من الفرن اكثر حرارة من بقية الفرن.

21. أسامة يقرأ سؤال متعددة الاختيارات في كتاب الفيزياء. ساعده في اختيار الاجابة الصحيحة لهذا السؤال: " التعرق يعمل على تبريد الجسم لان العرق الموجود على الجلد ..... "
a) يبلل سطح الجلد . فالاسطح المبلله تطرد الحرارة للخارج اسرع من السطوح الجافة.
b) يصرف الحرارة عبر المسام وينشرها بعيدا من خلال سطح الجلد.
c) له درجة حرارة مساوية لدرجة حرارة الجسم ، ولكنه يتبخر حاملا معه الحرارة بعيدا .
d) له درجة حرارة اقل قليلا من درجة حرارة الجسم ، حيث تنتقل كمية من الحرارة من الجسم الى العرق فيتبخر .

22. عندما استخدم زكريا المنفاخ لينفخ اطارات دراجته ، لاحظ ان المنفاخ اصبح حارا. تمعن في التعليلات التالية ، برأيك : ما هي افضل اجابة ؟
a) انتقلت الطاقة الى المنفاخ .
b) انتقلت درجة الحرارة الى المنفاخ .
c) انتقلت كمية من الحرارة من يده الى المنفاخ .
d) تسبب الجزء المعدني في المنفاخ في ارتفاع درجة الحرارة.

23. لماذا نلبس المعاطف في الاجواء الباردة ؟
a) لابقاء البرودة خارجا.
b) لتوليد الحرارة .
c) لتقليل كمية الحرارة المفقودة.
d) جميع ماسبق.

24. استخرج محسن مصاصة مثلجة من الفريزر ، كان قد وضعها في الامس . محسن اخبر الجميع ان درجة حرارة العصا الخشبية أعلى من درجة حرارة الجزء المثلج من المصاصة . تمعن في الاجابات التالية ، مع من تتفق ؟
a) مؤيد قال : انك على صواب . العصا الخشبية لا تصبح بنفس برودة الجزء المثلج .
b) قاسم قال : انك على صواب . لان الجزء المثلج يحوي برودة اكثر من العصا الخشبية.
c) طارق قال : انك مخطئ . هما يبدوان مختلفين لان العصا الخشبية تحوي كمية حرارة اكثر.
d) يوسف قال : انا اعتقد ان لهما نفس درجة الحرارة لانهما ملتصقان ببعض .

25. هاني يصف عرض تلفزيوني شاهده الليلة الماضية :" تمكن الفيزيائين من صنع مغناطيس فائق الموصلية ، عند درجة حرارة $-260°C$ " . تمعن في الاجابات التالية ، مع من تتفق ؟
a) معتز شكك في ذلك : لابد انك مخطئ . لا يمكن الحصول على درجة حرارة منخفضة الى هذا الحد !
b) عادل أجاب معترضا : نعم يمكن ذلك . لا يوجد حد ادنى لدرجات الحرارة المنخفضة .
c) زهير يعتقد ان هاني مصيب : أعتقد ان المغناطيس كان عند أدنى درجة حرارة ممكنه .
d) إبراهيم قال : انا اعتقد ان الموصلات فائقة الموصلية ، هي ايضا موصلة جيدة للحرارة . لذلك لا يمكن تبريدها الى مثل ذلك درجة الحرارة المنخفضة.

26. قال حسام : اختي الصغيرة دائما تلف لعبتها بالبطانية . ولكن مالا افهمه : لماذا هذه الدمية لا تصبح دافئة ؟
a) راجح قال : احتمال ان البطانية التي استخدمتها لم تكن عازلة جيدة للحرارة.
b) سجاد قال : احتمال ان البطانية التي استخدمتها لم تكن موصله جيدة للحرارة .
c) عصام قال : لان الدمى مصنوعة من مادة لا تحتفظ بالحرارة جيدا .
e) ماهر قال : لان الدمى مصنوعة من مادة تحتاج الى وقت اطول لتدفأ .
f) حسين قال : كلكم مخطئين.

Thermal Concept Evaluation (Student’s version)

استمارة تقييم مدى استيعاب الافراد لمفهومي الحرارة ودرجة الحرارة

15. مجموعة أصدقاء يستمعون إلى النشرة الجوية من خلال الراديو. المذيعة: "ستكون ليله قارصة البرودة مع درجة حرارة C°5، أبرد من الليلة الماضية حيث كانت C°10 ". تمعن في الإجابات التالية، مع من تتفق؟

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

a) جواد قال: ذلك يعني أن البرودة هذه الليلة ستكون ضعف برودة الليلة الماضية.
b) محمد قال: هذا غير صحيح. البرودة عند C°5 ليست ضعف البرودة عند C°10
c) راند قال: المذيعة جزئيا على صواب. ولكن يفترض بها أن تقول إن الـ C°10 أدفأ بمقدار الضعف من الـ C°5.
d) جمال قال: المذيعة جزئيا على صواب. ولكن يفترض بها أن تقول الـ C°5 أبرد بمقدار النصف من الـ C°10

16. اخرج ضياء مسطرتين من مقلمته، أحداهما معدنية والأخرى خشبية وأخبر الجميع أن المسطرة المعدنية تبدو أبرد من مثيلها الخشبية. تمعن في الإجابات التالية، أيها تفضل؟

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

a) المعدن يطرد الطاقة من يده بعيدا بشكل أسرع من الخشب.
b) الخشب مادة بطبيعتها أدفأ من المعدن.
c) المسطرة الخشبية تحوي كمية حرارة أكبر من مثيلتها المعدنية.
d) المعدن يعتبر مشع جيد للحرارة.
e) المعدن يعتبر مشع جيد للبرودة.

17. أخذ أيمن زجاجتين A،B تحويان ماء عند درجة حرارة C°20 وقام بلف الزجاجة A بمنشفة رطبة، والزجاجة B بمنشفة جافة. بعد مرور 20 دقيقة، قام بقياس درجة حرارة الماء في كلتاهما. درجة حرارة الماء الموجود في الزجاجة A كانت C°18 بينما كانت درجة حرارة الماء في الزجاجة B هي C°22. ماهي درجة حرارة الغرفة المتوقعة حين أجراء التجربة؟

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

a) C°26   b) C°21
c) C°20   d) C°18

18. أخذ وهب علبتين كرتون حليب الشكولاتة في نفس الوقت، أحداهما باردة من الثلاجة والأخرى دافئة من على طاولة المطبخ. برأيك لماذا العلبة المأخوذة من الثلاجة تبدو أبرد من الأخرى؟ مقارنة بالعلبة الدافئة، فإن العلبة الباردة:

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

a) تحوي برودة أكثر.
b) تحوي كمية حرارة اقل.
c) تعتبر موصل رديء للحرارة.
d) تمتص الحرارة بشكل أسرع من يد وهب.
e) توصل البرودة بشكل أسرع إلى يد وهب.

19. يعتقد راند أن أمه تطهي الحساء في طنجرة الضغط لأنها أسرع من الطناجر العادية. ولكنه لا يعرف السبب وراء ذلك. تمعن في الإجابات التالية، مع من تتفق؟ ملحوظة:(طناجر الضغط يكون لها غطاء محكم الأغلاق حتى يتسنى للضغط في الداخل بالارتفاع أعلى بكثير من الضغط الجوي).

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

a) احمد قال: ذك لان الضغط يتسبب في أن الماء يغلي إلى درجات حرارة اعلى من C°100.
b) حسن قال: ذلك لان الضغط العالي يولد كمية حرارة أكبر.
c) فادي قال: ذلك لان درجة حرارة البخار أكبر من درجة حرارة الحساء المغلي.
d) طاهر يقول: ذلك لان طنجرة الضغط توزع الحرارة خلال الطعام بشكل متساو.

20. بهاء يعتقد أن أمه تطهى الكيك في الرف العلوي للفرن الكهربائي، لأنها أكثر حرارة في الأعلى منها في الأسفل. تمعن في الإجابات التالية، برأيك: أيهم على صواب؟

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

a) تيسير قال: أنها أكثر حرارة في الأعلى، لان الحرارة تتحرك من الأسفل إلى الأعلى.
b) أمجد قال: أنها أكثر حرارة في الأعلى، لان الرف المعدني يعمل على تركيز الحرارة.
c) سعيد قال: أنها أكثر حرارة في الأعلى، لأنه الهواء عندما يسخن تقل كثافته ويرتفع للأعلى.
d) فارس يختلف معهم جميعا. فارس يقول: لا يمكن أن يكون الجزء العلوي من الفرن أكثر حرارة من بقية الفرن.

Thermal Concept Evaluation (Student's version)

استمارة تقييم مدى استيعاب الافراد لمفهومي الحرارة ودرجة الحرارة

21. أسامة يقرأ سؤال متعددة الاختيارات في كتاب الفيزياء. ساعده في اختيار الإجابة الصحيحة لهذا السؤال: "التعرق يعمل على تبريد الجسم لان العرق الموجود على الجلد .... "
a) يبلل سطح الجلد. فالأسطح المبللة تطرد الحرارة للخارج أسرع من السطوح الجافة.
b) يصرف الحرارة عبر المسام وينشرها بعيدا من خلال سطح الجلد.
c) له درجة حرارة مساوية لدرجة حرارة الجسم، ولكنه يتبخر حاملا معه الحرارة بعيدا.
d) له درجة حرارة اقل قليلا من درجة حرارة الجسم، حيث تنتقل كمية من الحرارة من الجسم إلى العرق فيتبخر.

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

22. عندما استخدم زكريا المنفاخ لينفخ إطارات دراجته، لاحظ أن المنفاخ أصبح حاراً. تمعن في التعليلات التالية، برأيك: ماهي أفضل إجابة؟
a) انتقلت الطاقة إلى المنفاخ.
b) انتقلت درجة الحرارة إلى المنفاخ.
c) انتقلت كمية من الحرارة من يده إلى المنفاخ.
d) تسبب الجزء المعدني في المنفاخ في ارتفاع درجة الحرارة.

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

مدى التأكد / مدى المعقولية

S

23. لماذا نلبس المعاطف في الأجواء الباردة؟
a) لإبقاء البرودة خارجا.
b) لتوليد الحرارة.
c) لتقليل كمية الحرارة المفقودة.
d) جميع ما سبق.

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

24. استخرج محسن مصاصة مثلجة من الفريزر، كان قد وضعها في الأمس. محسن أخبر الجميع أن درجة حرارة العصا الخشبية أعلى من درجة حرارة الجزء المثلج من المصاصة. تمعن في الإجابات التالية، مع من تتفق؟
a) مؤيد قال: أنك على صواب. العصا الخشبية لا تصبح بنفس برودة الجزء المثلج.
b) قاسم قال: إنك على صواب. لان الجزء المثلج يحوي برودة أكثر من العصا الخشبية.
c) طارق قال: أنك مخطئ. هما يبدوان مختلفين لان العصا الخشبية تحوي كمية حرارة أكثر.
d) يوسف قال: أنا اعتقد أن لهما نفس درجة الحرارة لانهما ملتصقان ببعض.

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

25. هاني يصف عرض تلفزيوني شاهده الليلة الماضية:" تمكن الفيزيائيين من صنع مغناطيس فائق الموصلية، عند درجة حرارة –260°C ". تمعن في الإجابات التالية، مع من تتفق؟
a) منير شكك في ذلك: لابد أنك مخطئ. لا يمكن الحصول على درجة حرارة منخفضة إلى هذا الحد!
b) عادل أجاب معترضا: نعم يمكن ذلك. لا يوجد حد أدني لدرجات الحرارة المنخفضة.
c) زهير يعتقد أن هاني مصيب: أعتقد أن المغناطيس كان عند أدنى درجة حرارة ممكنه.
d) إبراهيم قال: أنا اعتقد أن الموصلات فائقة الموصلية، هي أيضا موصلة جيدة للحرارة. لذلك لا يمكن تبريدها إلى مثل تلك درجة الحرارة المنخفضة.

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

26. قال حسام: أختي الصغيرة دائما تلف لعبتها بالبطانية. ولكن مالا افهمه: لماذا هذه الدمية لا تصبح دافئة؟
a) سلمان قال: احتمال أن البطانية التي استخدمتها لم تكن عازلة جيدة للحرارة.
b) سجاد قال: احتمال أن البطانية التي استخدمتها لم تكن موصله جيدة للحرارة.
c) عصام قال: لان الدمى مصنوعة من مادة لا تحتفظ بالحرارة جيدا.
d) ماهر قال: لان الدمى مصنوعة من مادة تحتاج إلى وقت أطول لتدفأ.
e) حسين قال: كلكم مخطئين.

متأكد جدا 7 6 5 4 3 2 1 تخمين
معقول جدا 7 6 5 4 3 2 1 غير معقول

ما هو مصدر إجاباتك لهذه الأسئلة (اختاري واحد أو أكثر)

☐ تخمين
☐ المنطق -السؤال نفسه
☐ المعلمة -الكتاب -موسوعة علمية -مرجع علمي -معلومات عامة
☐ الأهل -الأصدقاء
☐ تجربة شخصية
☐ الإعلام مثل: التلفزيون - الراديو - الأنترنت - الجرائد والمجلات
☐ اعتقاد ديني - العادات والتقاليد -المجتمع

وزارة التربية والتعليم
إدارة التخطيط والتطوير
الإدارة العامة للتربية والتعليم بالمنطقة الشرقية

Thermal Concept Evaluation (bubbles sheet)

Curtin University

استكشاف مدى استيعاب الأفراد
لمفهومي الحرارة ودرجة الحرارة

5_*_120

GradeCam ID

5	1	2	0

Exam Version: ① ② ③ ④ ⑤

1.	A	B	C	D	E	14.	A	B	C	D	E
2.	A	B	C	D	E	15.	A	B	C	D	E
3.	A	B	C	D	E	16.	A	B	C	D	E
4.	A	B	C	D	E	17.	A	B	C	D	E
5.	A	B	C	D	E	18.	A	B	C	D	E
6.	A	B	C	D	E	19.	A	B	C	D	E
7.	A	B	C	D	E	20.	A	B	C	D	E
8.	A	B	C	D	E	21.	A	B	C	D	E
9.	A	B	C	D	E	22.	A	B	C	D	E
10.	A	B	C	D	E	23.	A	B	C	D	E
11.	A	B	C	D	E	24.	A	B	C	D	E
12.	A	B	C	D	E	25.	A	B	C	D	E
13.	A	B	C	D	E	26.	A	B	C	D	E

معلومات شخصية (تبقى سرية وستستخدم لأغراض بحثية فقط)

1 حدد عمرك
a) 15   b) 16   c) 17   d) 18

2 الجنسية
a) سعودي   b) غير سعودي

3 نوع المدرسة
a) حكومية   b) خاصة   c) أخرى

4 نوع التعليم
a) تعليم عام   b) مقررات   c) أخرى

5 هل درست موضوع الطاقة الحرارية في أي مرحلة من مراحل دراستك؟
a) نعم   b) لا

8 أي المواضيع الفيزيائية التالية تأتي في المرتبة الأولى من حيث تفضيلك لها: (مدى الشعبية).
a) الميكانيكا   b) الحركة الموجية   c) الطاقة الحرارية   d) الكهرباء والمغناطيسية
e) الضوء   f) الصوت

ما هو مصدر اجاباتك لهذه الأسئلة (اختاري واحد أو أكثر).

A. تخمين   B. المنطق -السؤال نفسه   C. تجربة شخصية   D. المعلمة\ الكتاب المدرسي   E. الأنترنت

متأكد جدا   مدى التأكد من الإجابة 5 4 3 2 1   غير متأكد بالمرة

معقولة جدا   مدى معقولية الإجابة 5 4 3 2 1   غير معقولة بالمرة

Appendix D Consent and Information Forms

This appendix contains the English and Arabic consent forms that has been sent and singed by schools principals, teachers, parents and students, to participate in Thermal concept Evaluation and the Workshop.

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Parent Information Sheet

Dear Mr/Ms

My name is ASMAHAN AL SAFWAN. While teaching Year 11 science, I am also studying science education as a PhD student at Curtin University under the supervision of Professor David F. Treagust. I am currently working on a research project investigating students' misconceptions sources in Saudi High Schools. The study aimed at improving students' learning environment and enhance students' understanding, communication and confidence in learning physics concepts.

Your child's school principal has agreed to participate in this project. I would like to invite your child to take part in this study at school. The research procedures are as following:

- Some background informatiation about your child's school, teacher, will be collected.
- A Year 11 science class will be introduced to the thermal concept evaluation test TCE.
- Questionnaires and tests and one-on-one interviews will be used to evaluated students' conceptual understanding, communication skills and their attitudes towards study science .
- I will teach the scheduled science topic using the some activities to enhance students' learning.
- Some lessons will be recorded for analysis purposes
- Student progress will be collected during the implementation of the program

If you decide to allow your child to participate in this study, I will ask your child to finish a diagnostic test (TCE) and a student attitude questionnaire before and after the instruction of the topic. Keeping in mind, some of the participating students may be interviewed to elaborate on their learning experience, and your child could be one of them. The interview session will last for 20 minutes in a private space within the school and during school time. There will be a recorded of the interviewees' respondes.

Your child has also been provided with a letter and consent form from us and we encourage you to discuss with him/her what it means to participate in this research. Your child's involvement in this project is completely voluntary. You have the right to withdraw your consent to participate at any stage without any consequences to you or your child. When you and your child have signed the consent forms, please return them to me so that I know you and your child have agreed to participate and allowed us to use the data in this research.

The information gathered for this project will be kept confidential and private. Only the research investigator, ASMAHAN AL SAFWAN, and her supervisors, Professor David Treagust, and Dr Mihye Won will have access to the data (unless we are legally required to disclose the information under the Child Protection Policy of the Department of Education). The transcripts will not have the participant's name or any other identifying information. In adherence to the university policy, the recordings and transcripts will be kept in a locked cabinet for five years before a decision is made as to whether it should be destroyed. Once the research is completed, we will prepare a paper for publication in a professional journal. If you would like to learn about the research findings, please email us.

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval Number XXXXXXX). If you have any ethical concerns, you can contact the Human Research Ethics Committee at Curtin University (08 9266 9223 or hrec@curtin.edu.au). If you would like further information about the study, please feel free to contact me at school or my supervisor Professor David F.Treagust at 08 9266 7924 (D.Treagust@curtin.edu.au).

Thank you very much for your support for this research. Your child's participation is greatly appreciated.

Kind regards,

ASMAHAN AL SAFWAN

1 of 2

Consent and Information Forms/ English version

PARENT'S CONSENT FORM

- I understand the purpose and procedures of the study.
- I have been provided with the participation information sheet.
- I have been given the opportunity to ask questions about this research.
- I have discussed with my child what it means to participate in this project and he/she has agreed to participate as indicated by his/her signed consent form.
- I understand that the procedure itself may not benefit my child.
- I understand that my child's involvement is voluntary and I can withdraw at any time without problem.
- I understand that no personal identifying information like my child's name and address, or the name of the school will be used in any published materials.
- I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.
- I agree to allow my child to participate in the study outlined to me.

Name of Child: ______________________________

Name of Parent/Carer: ______________________________

Signature of Parent: ______________________________

Date: ______________________________

Consent and Information Forms/ English version

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Student Information Sheet

Dear

My name is ASMAHAN AL SAFWAN. While teaching Year11 science, I am also studying science education as a PhD student at Curtin University under the supervision of Professor David F. Treagust. I am currently working on a research project investigating students' misconceptions sources in Saudi High Schools. The study aimed at improving students' learning environment and enhance students' understanding, communication and confidence in learning physics concepts.

I would like to invite you to take part in this study at school. The research procedures are as following:

- Some background informatiation about your child's school, teacher, will be collected;
- A Year 11 science class will be introduced to the thermal concept evaluation test TCE;
- Questionnaires and tests and one-on-one interviews will be used to evaluated students' conceptual understanding, communication skills and their attitudes towards study science;
- I will teach the scheduled science topic using the some activities to enhance students' learning;
- Some lessons will be recorded for analysis purposes;
- Student progress will be collected during the implementation of the program.

If you decide to participate in this study, I will ask you to complete TCE and ATSM test before and after studying thermal energy topic. Some of the participating students may be interviewed to elaborate on their learning experience, and your could be one of them. The interview session will last for 20 minutes in a private space within the school and during school time. There will be a recorded of the interviewees' respondes.

Your school principal has agreed to participate in this project. Your parent has also been provided with a letter and a consent form and I encourage you to discuss what it means to participate in the research with your parent(s). Your involvement in this project is completely voluntary. If you don't want to be a part of this project, you can stop at any time without any consequences to you. When you sign the consent form, please return it to Mrs McLure so that I know you have agreed to participate in the research and allow me to use your data for this project.

The information you provide for this project will be kept confidential and private. This means I won't talk to other teachers, your parents, or peers about any individual students (unless I am legally required to disclose the information). This project won't go on your school record or count toward your science grade. The interview transcript won't have your name or any other identifying information on it. In adherence to the university policy, the interview records and transcripts will be kept in a locked cabinet for five years. If you wish to learn about the research results, please email me and I will provide a summary of research findings.

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval Number XXXXXX). If you have any ethical concerns, you can contact the Human Research Ethics Committee at Curtin University (9266 9223 or hrec@curtin.edu.au). If you would like further information about the study, please feel free to contact me at school or my supervisor Professor David F. Treagust at 08 9266 7924 (D.Treagust@curtin.edu.au).

Thank you very much for your support for this research.

Kind regards,

ASMAHAN AL SAFWAN

1 of 2

Consent and Information Forms/ English version

STUDENT'S CONSENT FORM

- I understand the purpose and procedures of the study.
- I have been provided with the participation information sheet.
- I have been given the opportunity to ask questions about this research.
- I have discussed with my parent(s) what it means to participate in this project.
- I understand that the procedure itself may not benefit me.
- I understand that my involvement is voluntary and I can withdraw at any time without problem.
- I understand that no personal identifying information like my name and address will be used in any published materials.
- I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.
- I agree to participate in the study outlined to me.

Name: ____

Signature: ____

Date: ____

Consent and Information Forms/ English version

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Principal Information Sheet

Dear Mr/Ms

My name is ASMAHAN AL SAFWAN. While teaching Year 11 science, I am also studying science education as a PhD student at Curtin University under the supervision of Professor David F. Treagust. I am currently working on a research project investigating students' misconceptions sources in Saudi High Schools. The study aimed at improving students' learning environment and enhance students' understanding, communication and confidence in learning physics concepts.

I am seeking your permission to conduct this research in your school. The research procedures are as following:

- Some background informatiation about your child's school, teacher, will be collected;
- A Year 11 science class will be introduced to the thermal concept evaluation test TCE;
- Questionnaires and tests and one-on-one interviews will be used to evaluated students' conceptual understanding, communication skills and their attitudes towards study science;
- I will teach the scheduled science topic using the some activities to enhance students' learning;
- Some lessons will be recorded for analysis purposes;
- Student progress will be collected during the implementation of the program.

If you decide to participate in this study, I will ask students to evaluate their learning using the TCE and ATSM to share their experience with us in a short interview. For those students who decide to participate in the study, I will ask them to complete TCE and ATSM test before and after studying thermal energy topic. Some of the participating students may be interviewed to elaborate on their learning experience, and your child could be one of them. The interview session will last for 20 minutes in a private space within the school and during school time. There will be a recorded of the interviewees' respondes.

I will liaise with the Head of middle school about: the most appropriate time to conduct the research; handing out parent and student information letters and collecting signed consent forms; and the most approriate way to accommodate non-participating students.

Your school's involvement in this project is completely voluntary. You have the right to withdraw your consent to participate at any stage without any consequences to you or your school. When you have signed the consent form, please return it to me so that we know you have agreed to participate and allow us to use the data in this research.

The information gathered for this project will be kept confidential and private. Only the research investigator ASMAHAN AL SAFWAN and her supervisors, Professor David Treagust and Dr Mihye Won will have access to the data. The transcripts will not have the participant's name or any other identifying information. In adherence to the university policy, the recordings and transcripts will be kept in a locked cabinet for five years before a decision is made as to whether it should be destroyed. Once the research is completed, we will prepare a paper to publish in a professional journal and a summary of that publication will be given to you.

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval Number XXXXXX). If you have any ethical concerns, you can contact the Human Research Ethics Committee at Curtin University (9266 9223 or hrec@curtin.edu.au). If you would like further information about the study, please feel free to contact me at school or my supervisor, Professor David F. Treagust at 08 9266 7924 (D.Treagust@curtin.edu.au)

Thank you very much for your involvement in this research. Your participation is greatly appreciated.

Kind regards,

ASMAHAN AL SAFWAN

Consent and Information Forms/ English version

PRINCIPAL'S CONSENT FORM

- I understand the purpose and procedures of the study.
- I have been provided with the participation information sheet.
- I understand that the procedure itself may not benefit me.
- I am willing to take part in this research project.
- I understand that my school's involvement is voluntary and I can withdraw at any time without problem.
- I understand that neither the school nor individual participants will be identified in any way in published materials.
- I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.
- I have been given the opportunity to ask questions about this research.
- I agree to allow students from my school to participate in the study outlined to me.

Name: ______________________________

Signature: ______________________________

Date: ______________________________

Consent and Information Forms/ Arabic version

المملكة العربية السعودية
وزارة التربية والتعليم
الإدارة العامة للتربية والتعليم بالمنطقة الشرقية
إدارة التخطيط والتطوير

وزارة التربية والتعليم
Ministry of Education

الرقم : ٣٥١٩٦٣٢١١
التاريخ : ١١/٩/ ١٤٣٥هـ
المشفوعات : ٦

الرؤية: الريادة لبناء جيل مبدع	الرسالة: تقديم خدمات تربوية وتعليمية ذات جودة عالية وفق معايير عالمية بمشاركة مجتمعية	القيم: المواطنة- الإتقان- العدل- العمل بروح الفريق- التنمية الذاتية- المسؤولية الإجتماعية

إلى: المكرمين مديري/مديرات مكاتب التربية والتعليم بكل من **حفظهم الله**
(شرق الدمام- غرب الدمام- القطيف- الخبر- رأس تنورة- الجبيل)
من: مديرة إدارة التخطيط والتطوير
بشأن: تسهيل مهمة الباحثة/ اسمهان آل صفوان

السلام عليكم ورحمة الله وبركاته ،،،

بناءً على موافقتنا بشأن تسهيل مهمة الباحثة/ اسمهان بنت معتوق آل صفوان طالبة الدراسات العليا لمرحلة الدكتوراه بجامعة كيرتن في أستراليا، والتي تجري بحثاً بعنوان (فهم طالبات المرحلة الثانوية في السعودية لمفهوم الطاقة الحرارية)، حيث يتطلب البحث تطبيق استبانة على جميع طالبات ومعلمات الفيزياء بالمرحلة الثانوية.

عليه فلا مانع من تسهيل مهمتها. علماً أن التطبيق سيكون من قبل الباحثة نفسها.

يسعدني شكركم على عنايتكم وتجاوبكم مع ظروف الباحثة.

والسلام عليكم ورحمة الله وبركاته ،،،

نوال بنت عبدالرحمن التيسان

١١/٩

م/الشامسي
١١/٩

فاكس ٨٢٦٤٩٧٧ ☎ ٨٢٦٩٣٦١ ✉ Office26@edueast.gov.sa

Consent and Information Forms/ Arabic version

المملكة العربية السعودية
وزارة التربية والتعليم
٢٨٠
الإدارة العامة للتربية والتعليم بالمنطقة الشرقية
إدارة التخطيط والتطوير

الرقم : —
التاريخ : ٨/٤/١٤٣٦هـ
المشفوعات : —

وزارة التربية والتعليم
Ministry of Education

الرؤية: الريادة لبناء جيل مبدع	**الرسالة:** تقديم خدمات تربوية وتعليمية ذات جودة عالية وفق معايير عالمية بمشاركة مجتمعية	**القيم:** المواطنة- الإتقان- العدل- العمل بروح الفريق- التنمية الذاتية- المسؤولية الإجتماعية

إلى من يهمه الأمر

الاسم:	أسمهان بنت معتوق صالح آل صفوان
الجهة التي يعمل/يدرس بها:	طالبة الدراسات العليا لمرحلة الدكتوراه بجامعة كيرتن للتكنولوجيا في أستراليا
الهاتف:	٠٠٦١٤١١٩٥٦٣٥٦
عنوان الدراسة:	(فهم طالبات المرحلة الثانوية في السعودية لمفهوم الطاقة الحرارية)
أداة الدراسة:	استبانة + مقابلة
العينة:	طالبات ومعلمات الفيزياء بالمرحلة الثانوية

تفيد الإدارة العامة للتربية والتعليم بالمنطقة الشرقية بأن المذكورة/ أسمهان بنت معتوق صالح آل صفوان ، قد أتمت إجراءات تسهيل مهمة الباحث لدى إدارة التخطيط والتطوير.

وبناءً على طلبها أعطيت هذه الإفادة.

الختم

٨/٤

وزارة التربية والتعليم
إدارة التخطيط والتطوير
الإدارة العامة للتربية والتعليم بالمنطقة الشرقية

مديرة إدارة التخطيط والتطوير

٨/٤

نوال بنت عبدالرحمن التيسان

Office26@edueast.gov.sa ☎ ٨٢٦٩٣٦١ فاكس ٨٢٦٤٩٧٧

اقرار مديرة

الى من يهمه الامر

اقر انا .... ، مديرة مدرسة .... ، انني وافقت على اجراء دراسة (قياس استيعاب الطالبات لمفاهيم الطاقة الحرارية) ، بناء على الامر الصادر من المدير العام، وانه تم اعلامي ان مشاركة مدرستي مشاركة طوعية، وان اي من البيانات التي سيتم جمعها اثناء الدراسة لن يتم الكشف عنها لاية جهة داخلية او خارجية ، وانها ستستخدم لاغراض بحثية بحته، دون ذكر لهوية الطالبات او اي من معلوماتهن الشخصية.

التوقيع:

اقرار معلمة

الى من يهمه الامر

اقر انا .... ، معلمة مادة ....، انني وافقت على اجراء دراسة قياس (استيعاب الطالبات لمفاهيم الطاقة الحرارية)، بناء على الامر الصادر من المدير العام، وانه تم اعلامي ان مشاركتي مشاركة طوعية، وان اي من البيانات التي سيتم جمعها اثناء الدراسة لن يتم الكشف عنها لاية جهة داخلية او خارجية ، وانها ستستخدم لاغراض بحثية بحته، دون ذكر لهوية الطالبات او اي من معلوماتهن الشخصية.

التوقيع:

اقرار طالبة

اقر انا الطالبة ....، انه تم اخباري ان المشاركة في اختبار(استيعاب مفاهيم الطاقة الحرارية) طوعي؛ وان معلوماتي الشخصية لن يدلى بها لاي احد داخل المدرسة او خارجه، وانما ستستخدم لاغراض بحثية فقط.

التوقيع:

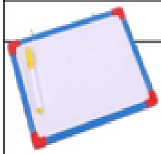
Appendix E The Workshop

This appendix contains an example of some the Workshop activates, Workshop venue, Workshop tools, and Workshop activates booklet

النشاط الرابع والثلاثون:

	هل يمكن للجليد أن يوجد عند درجة 70 درجة مئوي؟
الإجابة	☐ نعم ☐ لا

النشاط الخامس والثلاثون:

	ماهي درجة الحرارة المتوقعة داخل الثلاجة – فريزر الثلاجة
الإجابة	

النشاط السادس والثلاثون:

	ماذا يعني أن درجة الحرارة داخل الفريزر -18 درجة مئوية؟
الإجابة	.... 

النشاط السابع و الثلاثون:

	هل يوجد حد ادنى لدرجات الحرارة ؟
الإجابة	☐ نعم ☐ لا

Appendix F Total Pre-Post Comparison

T-Test

School = 2

Paired Samples Statistics[a]

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TotalPre	5.84	51	2.493	.349
	TotalPost	5.02	51	3.265	.457

a. School = 2

Paired Samples Correlations[a]

		N	Correlation	Sig.
Pair 1	TotalPre & TotalPost	51	.059	.679

a. School = 2

Paired Samples Test[a]

		Paired Differences			
					95% Confidence Interval of the ...
		Mean	Std. Deviation	Std. Error Mean	Lower
Pair 1	TotalPre - TotalPost	.824	3.989	.559	-.298

Paired Samples Test[a]

		Paired ...			
		95% Confidence Interval of the ...			
		Upper	t	df	Sig. (2-tailed)
Pair 1	TotalPre - TotalPost	1.945	1.475	50	.147

a. School = 2

School = 3

Page 1

Paired Samples Statistics[a]

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TotalPre	5.36	73	1.953	.229
	TotalPost	6.01	73	1.904	.223

a. School = 3

Paired Samples Correlations[a]

		N	Correlation	Sig.
Pair 1	TotalPre & TotalPost	73	-.042	.722

a. School = 3

Paired Samples Test[a]

		Paired Differences			
					95% Confidence Interval of the ...
		Mean	Std. Deviation	Std. Error Mean	Lower
Pair 1	TotalPre - TotalPost	-.658	2.785	.326	-1.307

Paired Samples Test[a]

		Paired ...			
		95% Confidence Interval of the ...			
		Upper	t	df	Sig. (2-tailed)
Pair 1	TotalPre - TotalPost	-.008	-2.017	72	.047

a. School = 3

School = 4

Paired Samples Statistics[a]

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TotalPre	5.78	558	2.620	.111
	TotalPost	6.20	558	2.360	.100

a. School = 4

Paired Samples Correlations[a]

		N	Correlation	Sig.
Pair 1	TotalPre & TotalPost	558	.104	.014

a. School = 4

Paired Samples Test[a]

		Paired Differences			
					95% Confidence Interval of the ...
		Mean	Std. Deviation	Std. Error Mean	Lower
Pair 1	TotalPre - TotalPost	-.423	3.338	.141	-.701

Paired Samples Test[a]

		Paired ...			
		95% Confidence Interval of the ...			
		Upper	t	df	Sig. (2-tailed)
Pair 1	TotalPre - TotalPost	-.145	-2.993	557	.003

a. School = 4

School = 6

Paired Samples Statistics[a]

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TotalPre	3.69	13	1.109	.308
	TotalPost	7.23	13	1.964	.545

a. School = 6

Paired Samples Correlations[a]

		N	Correlation	Sig.
Pair 1	TotalPre & TotalPost	13	.303	.314

a. School = 6

Paired Samples Test[a]

		Paired Differences			
					95% Confidence Interval of the ...
		Mean	Std. Deviation	Std. Error Mean	Lower
Pair 1	TotalPre - TotalPost	-3.538	1.941	.538	-4.712

Paired Samples Test[a]

		Paired ...			
		95% Confidence Interval of the ...			
		Upper	t	df	Sig. (2-tailed)
Pair 1	TotalPre - TotalPost	-2.365	-6.571	12	.000

a. School = 6

School = 7

Paired Samples Statistics[a]

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TotalPre	4.98	47	2.069	.302
	TotalPost	6.49	47	2.726	.398

a. School = 7

Paired Samples Correlations[a]

		N	Correlation	Sig.
Pair 1	TotalPre & TotalPost	47	-.083	.580

a. School = 7

Paired Samples Test[a]

		Paired Differences			
					95% Confidence Interval of the ...
		Mean	Std. Deviation	Std. Error Mean	Lower
Pair 1	TotalPre - TotalPost	-1.511	3.556	.519	-2.555

Paired Samples Test[a]

		Paired ... 95% Confidence Interval of the ... Upper	t	df	Sig. (2-tailed)
Pair 1	TotalPre - TotalPost	-.466	-2.912	46	.006

a. School = 7

Appendix G Frequencies

Frequencies

Statistics

		Q1_A	Q2_B	Q3_B	Q4_B	Q5_B	Q6_B	Q7_C
N	Valid	742	742	742	742	742	742	742
	Missing	0	0	0	0	0	0	0

Statistics

		Q8_A	Q9_B	Q10_C	Q11_B	Q12_C	Q13_D	Q14_B
N	Valid	742	742	742	742	742	742	742
	Missing	0	0	0	0	0	0	0

Statistics

		Q15_B	Q16_A	Q17_A	Q18_D	Q19_A	Q20_C	Q21_D
N	Valid	742	742	742	742	742	742	742
	Missing	0	0	0	0	0	0	0

Statistics

		Q22_A	Q23_C	Q24_D	Q25_C	Q26_E
N	Valid	742	742	742	742	742
	Missing	0	0	0	0	0

Frequency Table

Q1_A

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	72	9.7	9.7	9.7
	C2	139	18.7	18.7	28.4
	C3	130	17.5	17.5	46.0
	C4	131	17.7	17.7	63.6
	C5	270	36.4	36.4	100.0
	Total	742	100.0	100.0	

Q2_B

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	92	12.4	12.4	12.4
	C2	73	9.8	9.8	22.2
	C3	339	45.7	45.7	67.9
	C4	180	24.3	24.3	92.2
	C5	58	7.8	7.8	100.0
	Total	742	100.0	100.0	

Q3_B

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	88	11.9	11.9	11.9
	C2	63	8.5	8.5	20.4
	C3	343	46.2	46.2	66.6
	C4	193	26.0	26.0	92.6
	C5	55	7.4	7.4	100.0
	Total	742	100.0	100.0	

Q4_B

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	76	10.2	10.2	10.2
	C2	65	8.8	8.8	19.0
	C3	355	47.8	47.8	66.8
	C4	175	23.6	23.6	90.4
	C5	71	9.6	9.6	100.0
	Total	742	100.0	100.0	

Q5_B

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	63	8.5	8.5	8.5
	C2	50	6.7	6.7	15.2
	C3	368	49.6	49.6	64.8
	C4	185	24.9	24.9	89.8
	C5	76	10.2	10.2	100.0
	Total	742	100.0	100.0	

Q6_B

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	78	10.5	10.5	10.5
	C2	47	6.3	6.3	16.8
	C3	353	47.6	47.6	64.4
	C4	201	27.1	27.1	91.5
	C5	63	8.5	8.5	100.0
	Total	742	100.0	100.0	

Q7_C

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	20	2.7	2.7	2.7
	C2	340	45.8	45.8	48.5
	C3	34	4.6	4.6	53.1
	C4	231	31.1	31.1	84.2
	C5	117	15.8	15.8	100.0
	Total	742	100.0	100.0	

Q8_A

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	32	4.3	4.3	4.3
	C2	103	13.9	13.9	18.2
	C3	170	22.9	22.9	41.1
	C4	257	34.6	34.6	75.7
	C5	180	24.3	24.3	100.0
	Total	742	100.0	100.0	

Q9_B

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	79	10.6	10.6	10.6
	C2	54	7.3	7.3	17.9
	C3	352	47.4	47.4	65.4
	C4	199	26.8	26.8	92.2
	C5	58	7.8	7.8	100.0
	Total	742	100.0	100.0	

Q10_C

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	13	1.8	1.8	1.8
	C2	215	29.0	29.0	30.7
	C3	41	5.5	5.5	36.3
	C4	334	45.0	45.0	81.3
	C5	139	18.7	18.7	100.0
	Total	742	100.0	100.0	

Q11_B

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	89	12.0	12.0	12.0
	C2	58	7.8	7.8	19.8
	C3	342	46.1	46.1	65.9
	C4	204	27.5	27.5	93.4
	C5	49	6.6	6.6	100.0
	Total	742	100.0	100.0	

Q12_C

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	22	3.0	3.0	3.0
	C2	214	28.8	28.8	31.8
	C3	32	4.3	4.3	36.1
	C4	278	37.5	37.5	73.6
	C5	196	26.4	26.4	100.0
	Total	742	100.0	100.0	

Q13_D

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	5	.7	.7	.7
	C2	108	14.6	14.6	15.2
	C3	46	6.2	6.2	21.4
	C4	357	48.1	48.1	69.5
	C5	226	30.5	30.5	100.0
	Total	742	100.0	100.0	

Q14_B

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	63	8.5	8.5	8.5
	C2	41	5.5	5.5	14.0
	C3	368	49.6	49.6	63.6
	C4	156	21.0	21.0	84.6
	C5	114	15.4	15.4	100.0
	Total	742	100.0	100.0	

Q15_B

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	106	14.3	14.3	14.3
	C2	80	10.8	10.8	25.1
	C3	325	43.8	43.8	68.9
	C4	156	21.0	21.0	89.9
	C5	75	10.1	10.1	100.0
	Total	742	100.0	100.0	

Q16_A

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	56	7.5	7.5	7.5
	C2	172	23.2	23.2	30.7
	C3	146	19.7	19.7	50.4
	C4	239	32.2	32.2	82.6
	C5	129	17.4	17.4	100.0
	Total	742	100.0	100.0	

Q17_A

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	48	6.5	6.5	6.5
	C2	151	20.4	20.4	26.8
	C3	154	20.8	20.8	47.6
	C4	246	33.2	33.2	80.7
	C5	143	19.3	19.3	100.0
	Total	742	100.0	100.0	

Q18_D

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	8	1.1	1.1	1.1
	C2	102	13.7	13.7	14.8
	C3	43	5.8	5.8	20.6
	C4	363	48.9	48.9	69.5
	C5	226	30.5	30.5	100.0
	Total	742	100.0	100.0	

Q19_A

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	35	4.7	4.7	4.7
	C2	92	12.4	12.4	17.1
	C3	167	22.5	22.5	39.6
	C4	258	34.8	34.8	74.4
	C5	190	25.6	25.6	100.0
	Total	742	100.0	100.0	

Q20_C

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	18	2.4	2.4	2.4
	C2	194	26.1	26.1	28.6
	C3	36	4.9	4.9	33.4
	C4	369	49.7	49.7	83.2
	C5	125	16.8	16.8	100.0
	Total	742	100.0	100.0	

Q21_D

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	12	1.6	1.6	1.6
	C2	158	21.3	21.3	22.9
	C3	39	5.3	5.3	28.2
	C4	348	46.9	46.9	75.1
	C5	185	24.9	24.9	100.0
	Total	742	100.0	100.0	

Q22_A

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	64	8.6	8.6	8.6
	C2	181	24.4	24.4	33.0
	C3	138	18.6	18.6	51.6
	C4	234	31.5	31.5	83.2
	C5	125	16.8	16.8	100.0
	Total	742	100.0	100.0	

Q23_C

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	17	2.3	2.3	2.3
	C2	168	22.6	22.6	24.9
	C3	37	5.0	5.0	29.9
	C4	381	51.3	51.3	81.3
	C5	139	18.7	18.7	100.0
	Total	742	100.0	100.0	

Q24_D

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	7	.9	.9	.9
	C2	125	16.8	16.8	17.8
	C3	44	5.9	5.9	23.7
	C4	402	54.2	54.2	77.9
	C5	164	22.1	22.1	100.0
	Total	742	100.0	100.0	

Q25_C

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	9	1.2	1.2	1.2
	C2	172	23.2	23.2	24.4
	C3	45	6.1	6.1	30.5
	C4	357	48.1	48.1	78.6
	C5	159	21.4	21.4	100.0
	Total	742	100.0	100.0	

Q26_E

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C1	2	.3	.3	.3
	C2	215	29.0	29.0	29.2
	C3	2	.3	.3	29.5
	C4	425	57.3	57.3	86.8
	C5	98	13.2	13.2	100.0
	Total	742	100.0	100.0	

Bar Chart

Appendix H Unreliable Translation

This Appendix contains an example and the cover page of unreliable translation that used in Saudi Physics 4 where heat convection translated to heat pregnancy. These materials was written and edited by Saudi authors and been taught widely to hundreds of thousands of high school students between 2005 and 2011

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فيزياء (٤)

Physics (4)

التعليم الثانوي (نظام المقررات)

مسار العلوم الطبيعية

(الضوء - الإلكترونيات - الميكانيكا الحرارية)

الإعداد

أ.دلال عبد القادر مخلص — أ.ربى حسن حسونة

أ.لمياء أحمد محمد وزة — أ.بدرية محمد فلاتة

المراجعة والتعديل

د.عمر بن مرزوق الدوسري — أ.عبد العزيز بن إبراهيم الريّس

أ.عبد الله بن فهد الحنوش

طبعة تجريبية
١٤٣١ - ١٤٣٢هـ
٢٠١٠ - ٢٠١١ م

يوزع مجاناً ولا يباع

ثانيًا : انتقال الحرارة بالحمل Heat Transfer Pregnancy : Convection

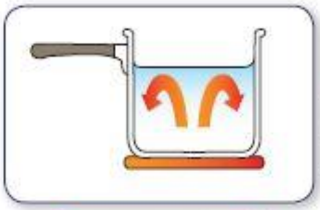
كما تعلم فإن سطح البحر إذا تعرض لعاصفة باردة فإنه يبرد وتزداد كثافته فيتحرك إلى أسفل ويصعد بدلاً منه ماء دافيء من قاع البحر إلى سطح البحر .

نسمي هذه العملية بالحمل حيث تقوم جزيئات الماء بحمل الحرارة أثناء حركتها وهو لا يحدث إلا إذا وجد اختلاف بين درجتي حرارة منطقتين من المائع ، وهو يحدث في الهواء بنفس طريقة حدوثه في الماء .

أنواع الحمل :

١- حمل طبيعي :

وفيه يعمل اختلاف درجة الحرارة على إحداث فرق في كثافة المائع في مناطقه المختلفة ، وينتج عن ذلك حركة للمائع حيث تنتقل جزيئات المائع ذات الكثافة المنخفضة إلى أعلى بينما تنتقل جزيئات المائع ذات الكثافة الاكبر إلى أسفل وتنتقل الطاقة الحرارية معها .



شكل (٣-٢١)

أعط أمثلة من الطبيعة على ظاهرة الحمل الطبيعي وأثرها في مجال الرؤية وفي حدوث الأعاصير

٢- حمل قسري Forced Pregnancy : Forced convection

وفيه تنتقل الطاقة الحرارية نتيجة لحركة المائع الناتجة عن استعمال جهاز ضخ ميكانيكي يعمل على تحريك المائع ومثال ذلك المروحة داخل الفصل التي تحرك الهواء وكذلك مضخة الماء التي تحرك الماء داخل محرك السيارة .

- **علل : يفضل وضع أجهزة تكييف الهواء وأجهزة التبريد (الفريزرات) في الأعلى.**
- **علل : يوضع مجمد الثلاجة في أعلاها .**
- **علل : توضع الدفاية في الأركان السفلية.**

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Mario

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The Physics Teacher 39, 496 (2001); doi: 10.1119/1.1424603

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MC

Micki Chi <mtchi@asu.edu>
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